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**FINAL REPORT – VEHICLE ARMOR STRUCTURE AND TESTING FOR FUTURE
COMBAT SYSTEM**

TARDEC Contract No. W56HZV-09-C-L550

Prepared for:

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EXECUTIVE SUMMARY

This report fulfills the requirements of the contract W56HZV-09-C-L550 (FY09) between Lawrence Technological University (LTU) and the United States Army Tank Automotive Research Development and Engineering Center (TARDEC). In addition, this report summarizes the material testing results of the contract W56HZV-08-C-0236 Work Directive (WD) 00017 (FY08). Both contracts include the material testing of similar composite materials using the same testing procedures. Therefore, the material testing of both contracts is included in this report.

FY08 included two materials and FY09 included six materials. Some materials have the same combination of resin and fibers and were only differentiated by the nominal thickness of the composite panel when fabricated. Overall, there were four fiber/resin combinations tested: (1) Huntsman PolyUrethane (PU) Rencast 6405 with S2-Glass, (2) Applied Poleramic (API) SC-15 Epoxy with S2-Glass, (3) Applied Poleramic SC-15 Epoxy with S2-Glass and Fill with Aramid Z-Fibers, and (4) Huntsman PolyUrethane Rencast 6405 with Ductile Hybrid Fabric.

The material properties include tensile elastic modulus, tensile strength, Poisson's ratio when the specimens are subjected to tensile loads, compressive elastic modulus, compressive strength, Poisson's ratio when the specimens are subjected to compressive load, shear modulus, and shear strength. All of these properties were measured with respect to all three material axes and therefore results include both in-plane (in the plane of the fibers) and out-of-plane properties. All material properties were measured at three test temperatures; (1) -40°F, (2) 70°F, and (3) 140°F.

Seven test types were used to determine the material properties. The testing procedures are discussed in detail in this report. The test types include; (1) in-plane tension, (2) in-plane compression, (3) in-plane shear, (4) out-of-plane tension, (5) out-of-plane compression, (6) out-of-plane shear, and (7) out-of-plane Poisson.

The results indicate that the nominal material thickness has no direct influence on the material property testing results. Strength and stiffness properties decrease with an increase in test temperature. The results of materials with Huntsman PU Rencast 6405 are more significantly influenced by temperature in comparison to the results of materials with API SC-15 Epoxy. The Poisson's ratio results of composite materials are scattered and trends are difficult to identify.

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CHAPTER 1: INTRODUCTION

1.1 Introduction and Background

This report summarizes all of the research efforts required to complete the contract W56HZV-09-C-L550 (FY09) between Lawrence Technological University (LTU) and the United States Army Tank Automotive Research Development and Engineering Center (TARDEC). In addition, this report summarizes the material testing results of the contract W56HZV-08-C-0236 Work Directive (WD) 00017 (FY08). Both include the material testing of composite materials using the same testing procedures. Therefore, all material testing is considered as one combined project and this report summarizes all of the findings. FY08 included two materials and FY09 included six materials. The FY08 test plan was under a subcontract with Mississippi State University.

Fiber-based composites are used more and more frequently for several applications in the military, the construction industry, the transportation industry, and other industries. Composites are currently being used or being considered for both personal and vehicle ballistic protection. Fiber reinforced composites are also used for vehicle components since they are lightweight with favorable strength and stiffness properties.

Traditionally, the fibers within composite materials are oriented along two axes designating a plane associated with the fibers. In design, composites are oriented such that the fibers resist the applied normal stresses. Normal stresses are distributed to and therefore resisted by both the fibers and the resin. Test standards have been established for testing composite materials in tension, shear, or compression in which stresses are resisted by the fibers (“in-plane”). However, the through thickness (“out-of-plane”) material properties are often not influential in the design. In out-of-plane tension, the load is primarily resisted by the strength of the resin [1].

Unique loading scenarios can cause high out-of-plane stresses in composites used for components in ground vehicles. The high stresses that develop from interlaminar shear and out-of-plane tension can result in premature failure of the material. Capacities associated with interlaminar shear and out-of-plane tension are influenced by the interlaminar bonding.

Graham [2] indicates that thin-shell theory cannot be used for composite structures since; they tend to be thicker than equivalent steel structures, the through-thickness modulus is normally much

lower than the in-plane moduli, the through-thickness shear modulus can be significantly lower than the in-plane moduli giving rise to significant shear deformation, and the interlaminar (out-of-plane) strength is much smaller than the in-plane strength.

Accessibility of the through-thickness stiffness and strength properties of composites are extremely limited, and testing methods are unclear [3]. Current test standards have been established for measuring the out-of-plane tension strength of composites [4]. However, several issues are encountered when performing the test. In order to test the material, a bond stronger than the strength of the material tested must exist between the specimen and the test fixture. Finding an epoxy with this level of strength is cumbersome, especially considering that it is used to bond two different materials.

Hara et al. [5] studied the out-of-plane tensile strength of CFRP laminates using the direct tensile method with specimens of various size and geometry. In this research, the authors considered experimental and analytical testing of spooled specimens and cylindrical specimens which were connected to metal end tabs. The authors indicated that testing should be performed on spooled specimens. In addition, thick specimens provide a more accurate measurement of the uniaxial and uniform tensile strength.

If the initial composite plate has a small thickness which is the case discussed in this report, spooling to a reduced gage section may be difficult to achieve. Other out-of-plane properties of interest for the research presented in this report include the compressive properties, the shear properties, and the Poisson's ratio. Very limited research has been performed on how to measure these properties for a particular laminate. Test methods must be established to obtain these properties and to therefore understand the complete material behavior of a composite system.

The primary objective of this research is to determine the strength and stiffness properties (tension, compression, and shear) of new innovative composites in all three material orientations (x, y, z) and under a wide range of temperatures using small-scale environmental chambers and high capacity load frames.

This report also discusses the testing procedures used to measure each material property. The testing matrix includes 7 "test types" as discussed in Section 1.3.3. Acceptance tests were performed to validate each of the test types. Some critical issues that had to be addressed during

the acceptance testing include instrumentation, equipment, setup, attachment of specimens to equipment, data acquisition, required number of tests, data reporting, and manpower requirements. All tests were performed and validated using ASTM standards when available. In addition, for properties that could not be measured using available ASTM standards, modified testing procedures were developed and validated during the acceptance testing.

1.2 Research Objectives

The objectives of this research project are summarized as follows:

- Identify applicable standards that can be used to determine the material properties of composite materials in all three material axes considering tension, compressive, and shear loading.
- Determine the specific testing procedures and other requirements necessary for testing the composite materials within the project scope.
- Develop new testing methods in which existing standards are unavailable for measuring specific properties of composite materials considering the design thickness of the material.
- Determine the material properties (strength and stiffness under compressive, tensile, and shear loads) of the eight composite materials.
- Determine the material properties at temperatures ranging from -40°F to 140°F
- Develop comparisons that investigate the influence of material thickness, composition of the composites, test temperature, and direction of load on the material properties.

1.3 Test Plan

The following subsections discuss the general test plan and therefore summarize the overall scope of work. Section 1.3.1 discusses the goals of the acceptance testing which was required to determine and validate the testing procedures used to measure the properties under a range of temperatures. Section 1.3.2 summarizes the eight materials included in the scope of work. Information is included about the composition of resin and fibers for each material and also the nominal thickness of the composite plate. Section 1.3.3 discusses the material properties that were measured and the test types used to measure these properties. Section 1.3.4 discusses the different temperatures that are considered and Section 1.3.5 discusses the number of specimens required to

obtain reliable statistical evidence of the results. Finally, Section 1.3.6 describes at what stress levels elastic properties were measured.

1.3.1 Acceptance Testing

In order to develop the material testing procedures, several iterations of “acceptance testing” were required. This work included the review of several ASTM standards and determining which standards are applicable for measuring the properties of composites. For some properties that could not be measured directly using the ASTM standards, the research team at LTU developed a new testing procedure using available ASTM standards as a guide.

During the acceptance testing, each step associated with the testing procedure was critically evaluated and presented to TARDEC. The testing procedure accommodated three chosen temperatures of -40°F, 70°F (ambient), and 140°F which will be discussed in more detail in Section 1.3.4. The number of specimens required to complete the acceptance testing was determined when the research team was confident that all material properties were adequately obtained and repeatable. Therefore, there was no specific number of specimens required to validate each test and limited results are presented in this report. The acceptance testing began in August, 2010 and was completed in April, 2011. However, actual material testing initiated for specific test types prior to the completion of all acceptance testing. The scope of work associated with the acceptance testing included but is not limited to the following:

- Determine the tests required to obtain all of the material properties required.
- Acquire all of the appropriate test fixtures to connect the specimen to the MTS and Instron load frames.
- Ensure user safety during testing.
- Obtain environmental chambers and construct frames that support the chambers in the load frames which would expedite the testing process.
- Determine the most appropriate strain gauges and strain gauge configurations for obtaining elastic properties at a range of temperatures.
- Determine the amount of time required to subject the specimens to the required temperature throughout the thickness.

1.3.2 Composite Materials Tested

The report contains the results of eight composite materials. However, some of the eight composite materials were composed of the same fiber and resin combination. The only difference between these materials was the nominal thickness of the composite plate when fabricated. The two materials included in the FY08 contract have been identified as Material 1-FY08 and Material 2-FY08. The six materials included in the FY09 contract have been identified as Material 1-FY09, Material 2-FY09, Material 3-FY09, Material 4-FY09, Material 5-FY09, and Material 6-FY09.

Table 1.3-1 shows the test matrix with respect to materials. In this table, information is given about the resin, the type of fibers, the orientation of the fibers, and the nominal thickness of the composite plate when fabricated.

Table 1.3-1: Composite Material Test Matrix

| Material | Resin | Fiber(s) | Fiber Orientation | Nominal Thickness 't' (in) |
|-----------------|--|--|------------------------------|----------------------------|
| Material 1-FY08 | Applied Poleramic (API) SC-15 Epoxy | S2-Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 1.5 |
| Material 2-FY08 | Huntsman PolyUrethane (PU) Rencast 6405 | S2-Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 1.5 |
| Material 1-FY09 | Huntsman PolyUrethane (PU) Rencast 6405 | S2-Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 1 |
| Material 2-FY09 | Huntsman PolyUrethane (PU) Rencast 6405 | S2-Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 0.75 |
| Material 3-FY09 | Applied Poleramic (API) SC-15 Epoxy | S2-Glass Warp and Fill with Aramid Z-Fiber | Modified Orthogonal Weave | 0.75 |
| Material 4-FY09 | Applied Poleramic (API) SC-15 Epoxy | S-2Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 1 |
| Material 5-FY09 | Applied Poleramic (API) SC-15 Epoxy | S2-Glass Plain Weave (PW) 24oz./yd. ² | 0/90, 45/-45 | 0.75 |
| Material 6-FY09 | Huntsman PolyUrethane (PU) Rencast 6405 | Ductile Hybrid Fabric (DHF), Ultra-high modulus carbon fibers, high modulus carbon fibers, E-glass fibers | 0, 45, -45 | 0.75 |

Material 1-FY08, Material 4-FY09, and Material 5-FY09 are all composed of Applied Poleramic (API) SC-15 Epoxy and S2-glass fibers. The nominal percent volume and orientation of fibers are identical. However, the material thickness of the three materials is 1.5 in., 1 in., and 0.75 in., respectively.

Material 2-FY08, Material 1-FY09, and Material 2-FY09 are all composed of Huntsman PolyUrethane (PU) Rencast 6405 and S2-glass fibers. The nominal percent volume and orientation

of fibers are identical. However, the material thickness of the three materials is 1.5 in., 1 in., and 0.75 in., respectively.

Material 3-FY09 is a 0.75 in. thick 3D hybrid panel with a modified orthogonal weave and will be referred to as the “3D-weave” material. S2-glass fibers are oriented within the assumed x-y plane and aramid fibers are oriented along the z-axis. This is the only material in which fibers were oriented along the z-axis. This product was developed by Textile Engineering and Manufacturing and is Style No 0018-01.

Material 6-FY09 consists of Huntsman PolyUrethane (PU) Rencast 6405 and Ductile Hybrid Fabric (DHF) [6]. This material will be identified as the “DHF” material. DHF uses a hybridization technique in which lower elongation fibers fail prior to higher elongation fibers. The system uses three different types of fibers. The lowest elongation (LE) fibers failure first, allowing a strain relaxation until the higher elongation (HE) fibers are proportioned to sustain the load until failure. The lowest elongation fibers are ultra-high modulus carbon fibers (Carbon No. 1). The highest elongation fibers are E-glass fibers. The medium elongation fibers are high-modulus carbon fibers (Carbon No. 2).

1.3.3 Material Properties and Test Types

The test matrix considers both elastic and ultimate strength properties of the materials. Table 1.3-2 summarizes the 7 “test types” which are discussed in detail in Chapter 2. The testing procedure accounts for measuring the tensile strength, the tensile modulus, the compressive strength, the compressive modulus, the shear strength, the shear modulus, and Poisson’s ratio with respect to all three material axes. Hence, the testing procedure obtains the complete multi-axis material properties of the composite materials.

In Table 1.3-2, ‘ E ’ represents the elastic modulus when subjected to uniaxial tensile stresses, ‘ EC ’ represents the elastic modulus when subjected to uniaxial compressive stresses, and ‘ G ’ represents the shear modulus. ‘ ν ’ represents the Poisson’s ratio when subjected to uniaxial tension stresses and ‘ νC ’ represents the Poisson’s ratio when subjected to uniaxial compressive stresses. ‘ ST ’ represents tensile strength, ‘ SC ’ represents compressive strength, and ‘ S ’ represents shear strength. Table 1.3-2 also lists the ASTM standard that was followed in order to perform the tests. For the out-of-plane compression and out-of-plane Poisson tests, no particular standard was

followed. However, loading rates and other useful information were obtained using ASTM D7291 when applicable.

A majority of the composites tested are quasi-isotropic with fibers oriented 90° apart from each other. Therefore, the material properties along either fiber axis are identical and only one of the ‘x’ or ‘y’ directions needs to be tested. This is reflected in the test data as shown later.

Table 1.3-2: Test Types and Properties Matrix

| # | Test Type | Elastic Properties | Strength Properties | ASTM Ref. |
|---|--------------------------|-------------------------|---------------------|-----------|
| 1 | In-Plane Tension | E_x, E_y, ν_{xy} | ST_x, ST_y | D 3039 |
| 2 | In-Plane Compression | EC_x, EC_y, ν_{Cxy} | SC_x, SC_y | D 6641 |
| 3 | In-Plane Shear | G_{xy} | S_{xy} | D 7078 |
| 4 | Out-of-Plane Tension | E_z | ST_z | D 7291 |
| 5 | Out-of-Plane Compression | EC_z | SC_z | D 7291* |
| 6 | Out-of-Plane Shear | G_{yz}, G_{xz} | S_{yz}, S_{xz} | D 5379 |
| 7 | Out-of-Plane Poisson | ν_{yz}, ν_{xz} | - | D 7291* |

*Modified Version of ASTM D7291

1.3.4 Test Temperatures

In collaboration with TARDEC, the researchers at LTU agreed that for each material and each test type, properties will be measured at three different temperatures. The testing procedure had to accommodate the three chosen temperatures of -40°F (cold), 70°F (ambient), and 140°F (hot). These temperatures were chosen to account for the temperature extremes in which a military ground vehicle may be exposed to during its service life.

Small-scale environmental chambers were obtained as discussed in more detail in Section 2.9. The test setup had to accommodate placing the specimens inside the chambers. Each environmental chamber had holes on the top and bottom that allowed either the specimen or fixture attachments to pass through into the chamber.

1.3.5 Number of Specimens Tested

For each material, each test type, and each test temperature, the testing was considered complete when five relatively consistent and reliable results were obtained for the elastic and strength

properties. Often, issues developed during the first five specimens tested. For example, multiple strain gauges were malfunctioning or debonding within the test setup. In addition, for some instances (especially under elevated temperatures), results were not consistent due to the nature of the material and the test being performed. Anywhere from five to fourteen specimens were tested and the final data set was composed of the five specimen results with the most reliable and consistent data. Therefore and not including the results of the acceptance testing, the results of 840 specimens (8 materials x 7 test types, x 3 temperatures x 5 specimens) are included in this report. Results determined unacceptable are not included in this report.

1.3.6 Calculation of Elastic Properties

All properties listed in Table 1.3-1 were determined for each material and each temperature by taking the average results of five specimens. Elastic properties were computed using changes in stresses and strains recorded when the load corresponded to 20% of the maximum load to when the load corresponded to 50% of the maximum load. For some instances, the linear portion of the stress-strain curve did not extend to 50% of the maximum load. When lower ranges were used, it is noted in Section 2.10. The ranges are also noted with the material testing results in the appendices. All elastic properties were computed for each specimen using the average value calculated using multiple strain gauges.

1.4 Specimen Nomenclature

The nomenclature that is used for each material specimen (i.e. non-acceptance testing) includes the material (e.g. 'MAT1' represents Material 1), the type of test conducted (e.g. 'TX' represents In-plane Tensile Test), the specimen number (e.g. '2' represents specimen 2 of 5), the temperature (e.g. '140' represents a temperature of 140°F, 'N40' represents a temperature of -40°F), and the contract fiscal year (e.g. FY08). An example nomenclature is: MAT1-TX-2-140-FY08.

For the acceptance testing, the material will be identified as MATA where "A" represents "Acceptance". The following nomenclature will be used for the different test types (Table 1.3-2).

- Test 1: 'TX' In-Plane Tension Test. Measures E_x and ST_x or E_y and ST_y
- Test 2: 'CX' In-Plane Compression Test. Measures EC_x and SC_x or EC_y and SC_y
- Test 3: 'SXY' In-Plane Shear Test. Measures S_{xy} and G_{xy}

- Test 4: ‘TZ’ Out-of-Plane Tension Test. Measures E_z and ST_z
- Test 5: ‘CZ’ Out-of-Plane Compression Test. Measures EC_z and SC_z
- Test 6: ‘SXZ’ Out-of-Plane Shear Test. Measures S_{xz} and G_{xz} or S_{yz} and G_{yz}
- Test 7: ‘OP’ Out-of-Plane Poisson Test. Measures ν_{xz} or ν_{yz}

1.5 Report Arrangement

Chapter 2 of the report describes the testing procedures associated with each “test type” identified in Table 1.3-2. Any deviations to the general testing procedure for specific materials are discussed in Section 2.10. Chapter 3 discusses the acceptance testing final results used to determine and validate the testing procedures described in Chapter 2. Chapters 4-7 provide the material testing results. The results of all materials that are composed of Applied Poleramic (API) SC-15 Epoxy and S2 Glass fibers are summarized in Chapter 4. The results of all materials composed of Huntsman PolyUrethane (PU) Rencast 6405 and S2 glass fibers are summarized in Chapter 5. Chapter 6 summarizes the results for the 3D weave material (Material 3-FY09) and Chapter 7 summarizes the results for the DHF material (Material 6-FY09). Chapter 8 provides a detailed discussion of the results including the results of a statistical analysis. Chapter 9 provides conclusions.

All material testing results are presented in the appendices. Appendix J shows the means, standard deviations, and coefficients of variances from results of five specimens tested.

- Appendix A: Acceptance Testing
- Appendix B: Material 1-FY08
- Appendix C: Material 2-FY08
- Appendix D: Material 1-FY09
- Appendix E: Material 2-FY09
- Appendix F: Material 3-FY09
- Appendix G: Material 4-FY09
- Appendix H: Material 5-FY09
- Appendix I: Material 6-FY09

CHAPTER 2: TESTING PROCEDURE

The following subsections describe each of the different test types listed in Table 1.3-2 in detail. Information is included on how the test is performed, material properties measured, equipment used, test fixtures used, strain gauge locations, etc. These testing procedures evolved from several iterations during the acceptance testing. Modifications to the testing procedure were required for specific materials and under specific temperatures. These modifications are discussed in Section 2.10.

2.1 Test 1: In-Plane Tensile Test

The in-plane tensile test was conducted using ASTM D 3039/D 3039M “Standard Test Method for Tensile Properties of Polymer Composite Materials” [7]. The test determines the in-plane elastic properties and strength properties of the composites. Load is applied within the same plane as the orientation of the fiber lamina. As shown in Table 1.3-2, this test was used to measure the elastic modulus, E_x or E_y , the tensile strength, ST_x or ST_y , and the in-plane Poisson’s ratio when subjected to tensile load, ν_{xy} (both x and y axes associated with fiber orientations). A uniaxial tension load is applied parallel the plane of the fibers at a test rate of 0.05 in/min.

The machine used to perform this test is an Instron 8502A two post load frame. The upper head of the test frame is a universal joint. The specimens were gripped in the wedge grips of the test machine. For most materials tested, special fixtures were fabricated to disallow the material from failing by crushing at the grips upon testing. When crushed, the specimens were found to have an increased width at the grips. Therefore, the fixtures were designed to maintain the width upon testing. In addition, a steel wire mesh was placed in between the specimen and the fixtures to further prevent slipping. The specimens were gripped to a nominal pressure of 1500 psi to 3000 psi. Figure 2.1-1 shows a photograph of steel fixtures used to maintain the specimen width (equal to thickness of nominal composite plate) and steel wire mesh. Figure 2.1-2 shows a picture of a uniaxial tension specimen within the heads of the test frame.

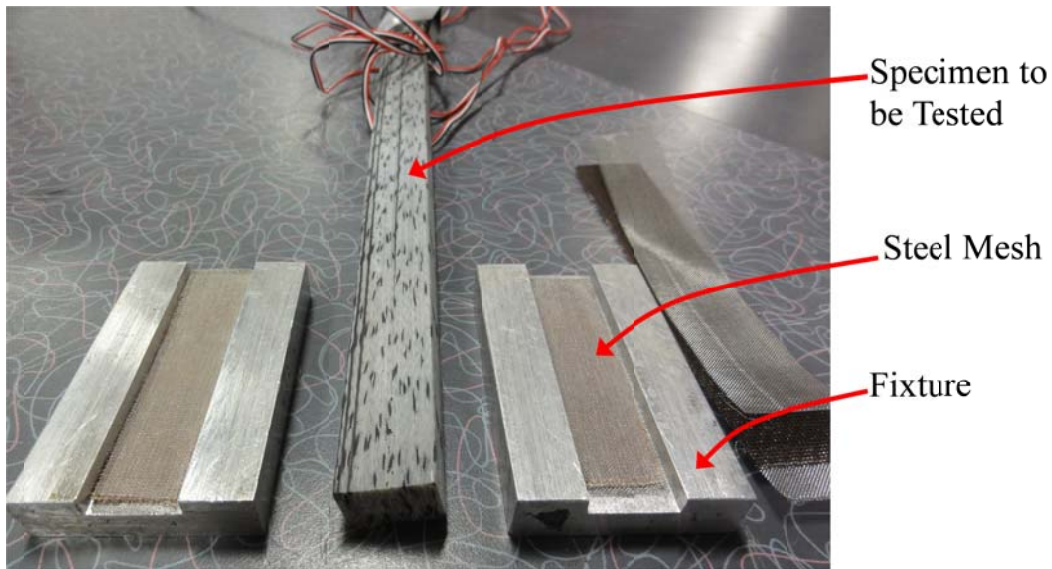


Figure 2.1-1: Steel Fixtures and Steel Mesh Used to Prevent Crushing and Slipping

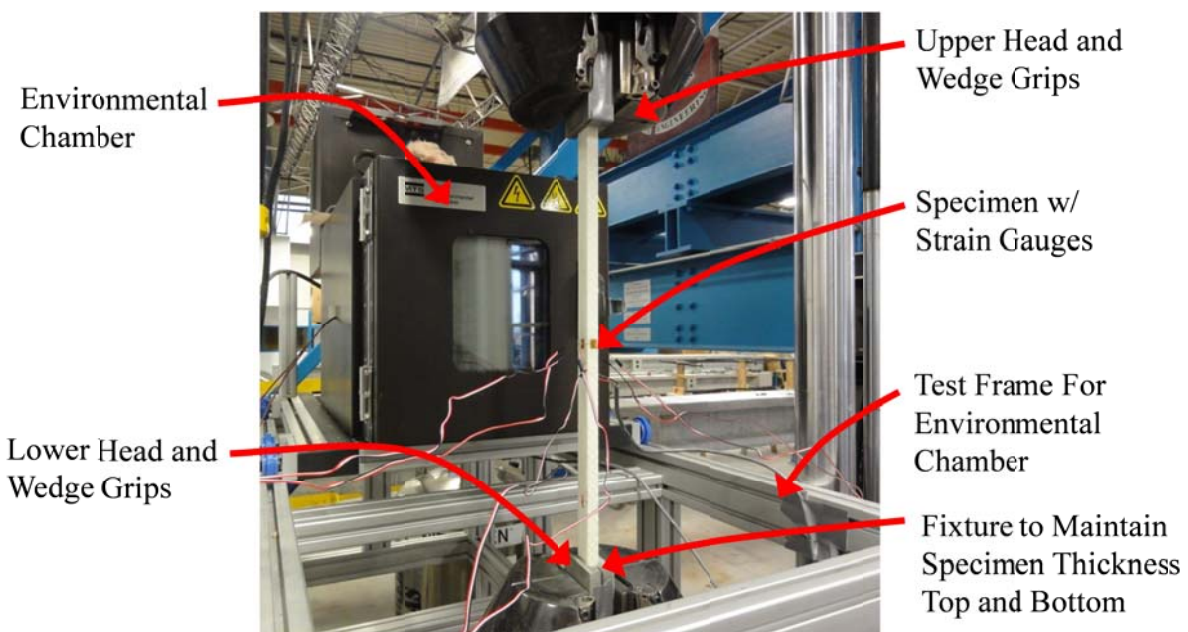


Figure 2.1-2: Test Setup for In-Plane Tension Test

2.1.1 Specimen Geometry

Figure 2.1-3 shows an illustration of the test specimen dimensions and the final chosen strain gauge configuration used to measure the elastic modulus and Poisson's ratio of the material. As shown in Figure 2.1-3, the test specimen has a nominal length of 26 in. The thinnest dimension of the specimen is 0.5 in. and the width of the specimen is equal to the nominal thickness of the material being tested, ' t ', as shown in Table 1.3-1. The thickness of 0.5 in. and the width were measured prior to testing to calculate average normal stresses.

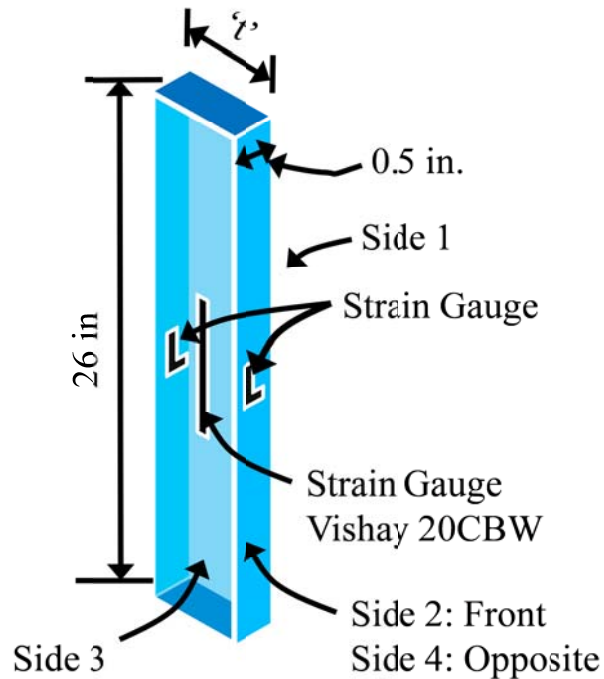


Figure 2.1-3: In-Plane Tension Test Specimen Dimensions and Strain Gauge Locations

2.1.2 Strain Gauge Setup

As shown in Figure 2.1-3, the different sides of the specimen have been identified as Side 1, Side 2, Side 3, and Side 4 (typical for all test types with rectangular specimen dimensions). One longitudinal strain gauge was adhered on each of the four sides of the specimen to measure the longitudinal strain (ϵ_l). These strain gauges are used to calculate the elastic modulus (E_x or E_y). On one side (Side 1), a Vishay N2A-06-20CBW-350 (20CBW) strain gauge is attached to the specimen. This is a longer gauge (approximately 2.5 in.) and is used to verify the measurements of

the other three strain gauges over a longer length. Three C2A-06-125-LT (125LT) strain gauges were used on the other three sides of the specimen. For each specimen, the average elastic modulus determined from the four strain gauges was reported. The 125LT strain gauge also measures the transverse strain (ε_t) (i.e. strain in the direction perpendicular to the applied load) to calculate the “in-plane” Poisson’s ratio of the material. The transverse strain gauge readings are only recorded on Sides 2 and 4.

The final strain gauge configuration was modified a number of times during testing depending on the material and the time when the specimens were tested. Therefore, strain gauge configurations as shown in the appendices may vary from the final configuration chosen. The final configuration of strain gauges allows the researchers to identify the required elastic properties and determine if bending occurs during testing or if initial imperfections exist in the specimen geometry. The latter two issues will result in unequal readings on either side of the specimen.

2.1.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Tensile strength (ST_x or ST_y) is calculated as:

$$ST_x = P_{\max} / A$$

P_{\max} is the force at fracture and A is the original cross-sectional area of the specimen.

- Longitudinal stress (σ_x or σ_y) is calculated at any load level P as:

$$\sigma_x = P/A$$

- Modulus of elasticity (E_x or E_y) is calculated as:

$$E_x = \Delta\sigma_x / \Delta\varepsilon_x$$

- Change in stress $\Delta\sigma_x$ and strain $\Delta\varepsilon_x$ readings are taken from the linear portion of the σ - ε curve which was usually between when the load corresponded to 20% of the axial load capacity and 50% of the axial load capacity unless noted in Section 2.10.

- Poisson’s ratio (ν_{xy}) is calculated as:

$$\nu_{xy} = - \Delta\varepsilon_t / \Delta\varepsilon_l$$

- ε_t is the transverse strain and ε_l is the longitudinal strain, taken from the linear portion of the σ - ε curve

2.2 Test 2: In-Plane Compression Test

The in-plane compressive test is conducted using ASTM D 6641/D 6641M [8], “Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture”. As shown in Table 1.3-2, this test is used to calculate the compressive strength, SC_x or SC_y , the elastic modulus, EC_x or EC_y , and the in-plane Poisson ratio, $\nu_{C_{xy}}$ when subjected to compressive loads.

The machine used to perform this test is an MTS 311 four post load frame with fixed heads. The compression fixture used to test the material was designed using ASTM D6641 and built by Material Testing Technology (MTT). Two illustrations of the fixture are shown in Figures 2.2-1 and 2.2-2. The MTS test machine was fitted with compressive platens that meet the ASTM requirements. The specimens were loaded at a rate of 0.05 in/min. Figure 2.2-3 shows a picture of a specimen within the compression fixture and the MTS.

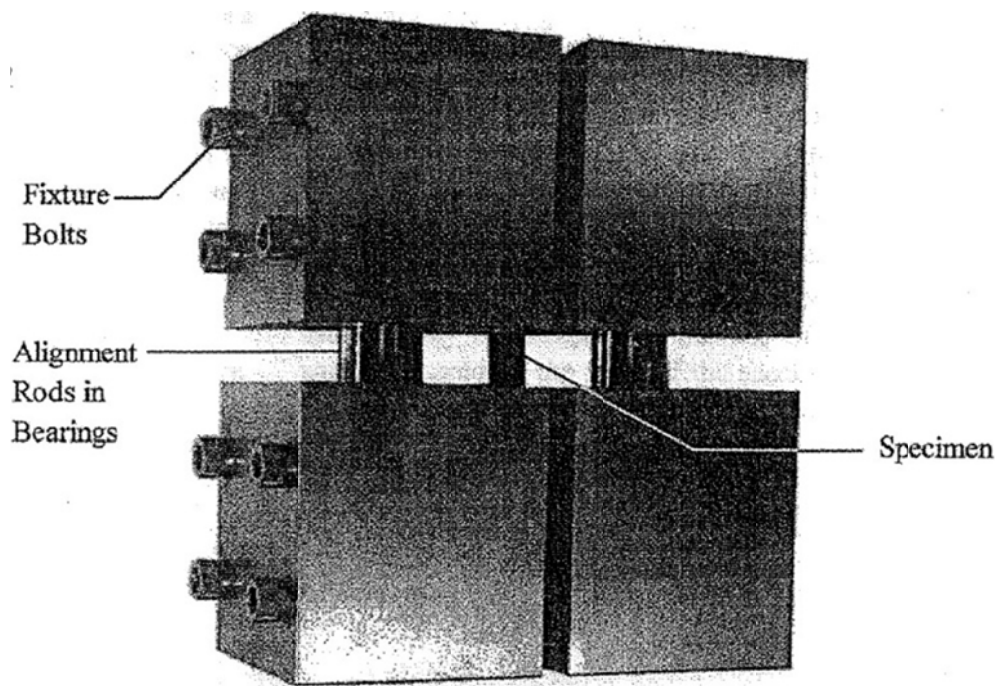


Figure 2.2-1: Combined Loading Compression (CLC) Test Fixture [8]

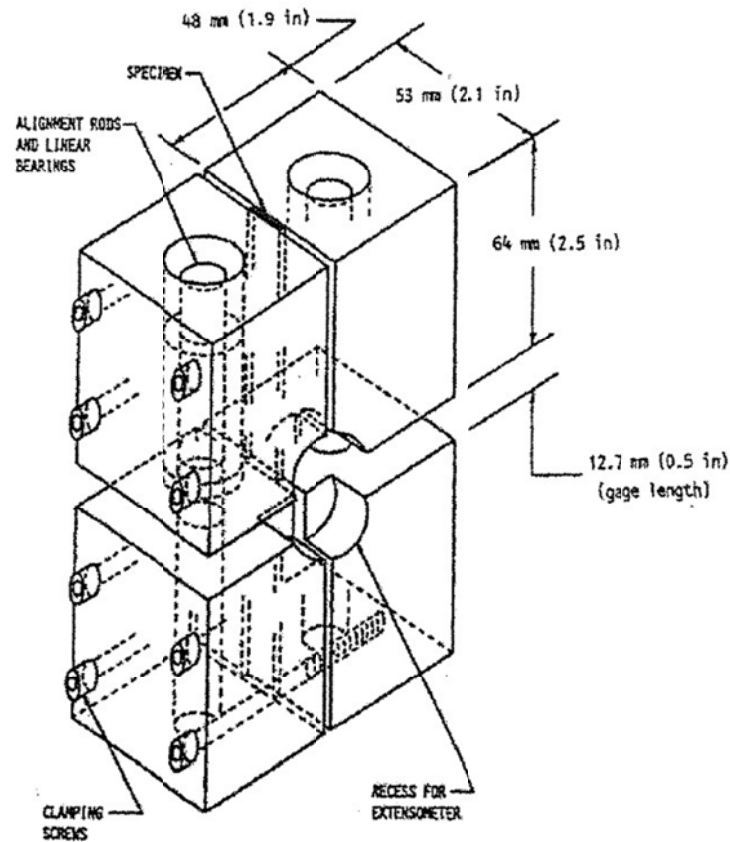


Figure 2.2-2: Combined Loading Compression (CLC) Test Fixture [8]

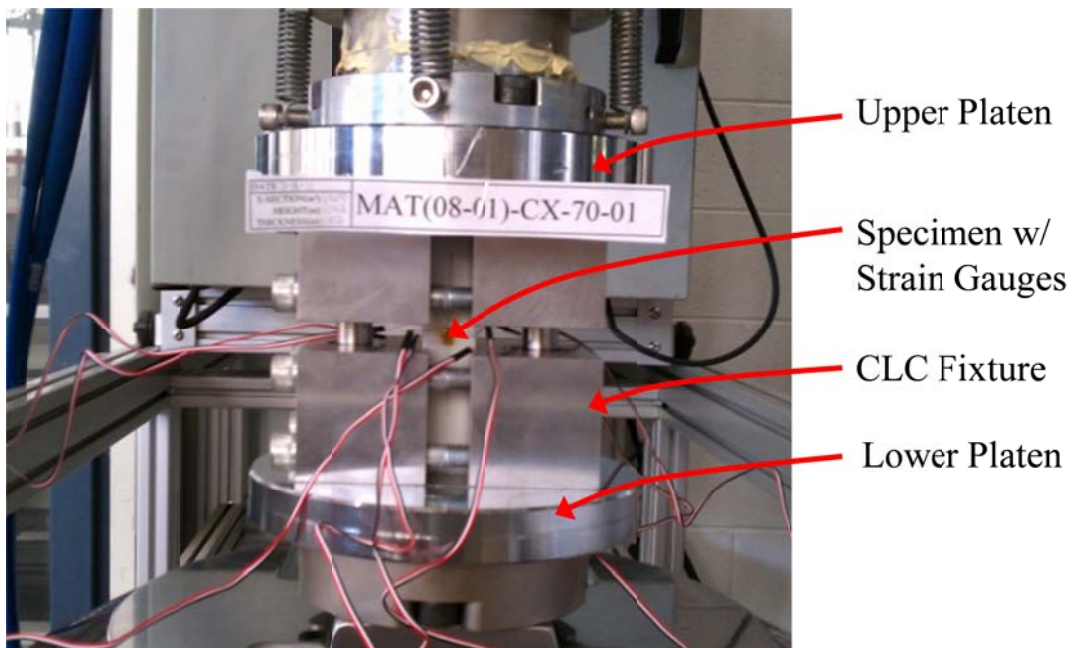


Figure 2.2-3: Test Setup for In-Plane Compression Test

2.2.1 Specimen Geometry

Figure 2.2-4 shows an illustration of the test specimen dimensions and the final chosen strain gauge configuration used to measure the elastic modulus and Poisson's ratio of the material when subjected to compressive loads. The test specimen has a nominal length of 5.5 in. The width of the specimen is 1.0 in. and the thickness of the specimen is equal to the thickness of the composite plate when fabricated, ' t '. The width and the thickness were measured prior to testing to obtain accurate cross-sectional areas when computing the average normal stress.

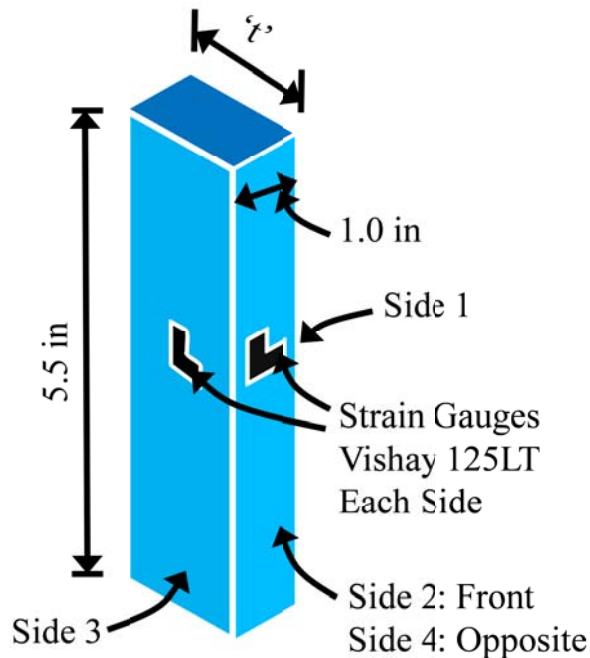


Figure 2.2-4: In-Plane Compression Specimen Dimensions and Strain Gauge Locations

2.2.2 Strain Gauge Setup

Four Vishay C2A-06-125-LT strain gauges are attached to each specimen, one on each of the four sides identified in Figure 2.2-4. These strain gauges are capable of measuring both the longitudinal and transverse strain. However, the transverse strains were only analyzed on Sides 2 and 4 (see Figure 2.2-4) in order to calculate the in-plane Poisson's ratio. The final elastic modulus and Poisson's ratio reported for each test was computed as the average as interpreted from each individual gauge.

2.2.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Compressive strength (SC_x or SC_y) is calculated as:

$$SC_x = P_{\max} / A$$

P_{\max} is the maximum force at failure and A is the cross-sectional area of the specimen.

- Longitudinal stress (σ_x or σ_y) is calculated at any load level P as:

$$\sigma_x = P/A$$

- Modulus of elasticity (EC_x or EC_y) is calculated as:

$$EC_x = \Delta\sigma_x / \Delta\epsilon_x$$

- Change in stress $\Delta\sigma_x$ and strain $\Delta\epsilon_x$ readings are taken from the linear portion of the σ - ϵ curve which was typically between when the load corresponds to 20% of the axial load capacity and 50% of the axial load capacity unless noted in Section 2.10.

- Poisson's ratio ($\nu_{C_{xy}}$) is calculated as:

$$\nu_{C_{xy}} = - \Delta\epsilon_t / \Delta\epsilon_l$$

- ϵ_t is the transverse strain and ϵ_l is the longitudinal strain, taken from the linear portion of the σ - ϵ curve.

2.3 In-Plane Shear

The in-plane shear test is conducted using ASTM D 7078/D 7078M [9] "Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method". In-plane refers to the fiber orientation with respect to the test. Fibers are oriented along the length of the specimen and along the width of the specimen. As shown in Table 1.3-1, the test is used to determine the in-plane shear strength, S_{xy} , and the in-plane shear modulus, G_{xy} .

The machine used to perform this test is an MTS 311 four post load frame with fixed heads. The fixture used was designed per ASTM D 7078/D 7078M and built by MTT. The shear specimens were clamped on each end between two pairs of loading rails creating a shear force with the notched section of the shear specimen subjected to the highest shear stress. The specimens were loaded at a rate of 0.05 in/min. The initial shear fixture used to perform the experimental investigations was found to be inadequate for the shear strength of these particular composite

materials. Therefore, a specially designed shear fixture was fabricated to accommodate the shear stress capacity. Figure 2.3-1 shows a picture of the shear fixture within the MTS. In Figure 2.3-1, the location of the specimen is noted. The ‘torque bolts’ identified in Figure 2.3-1 were tightened to a torque of 40 ft-lb.

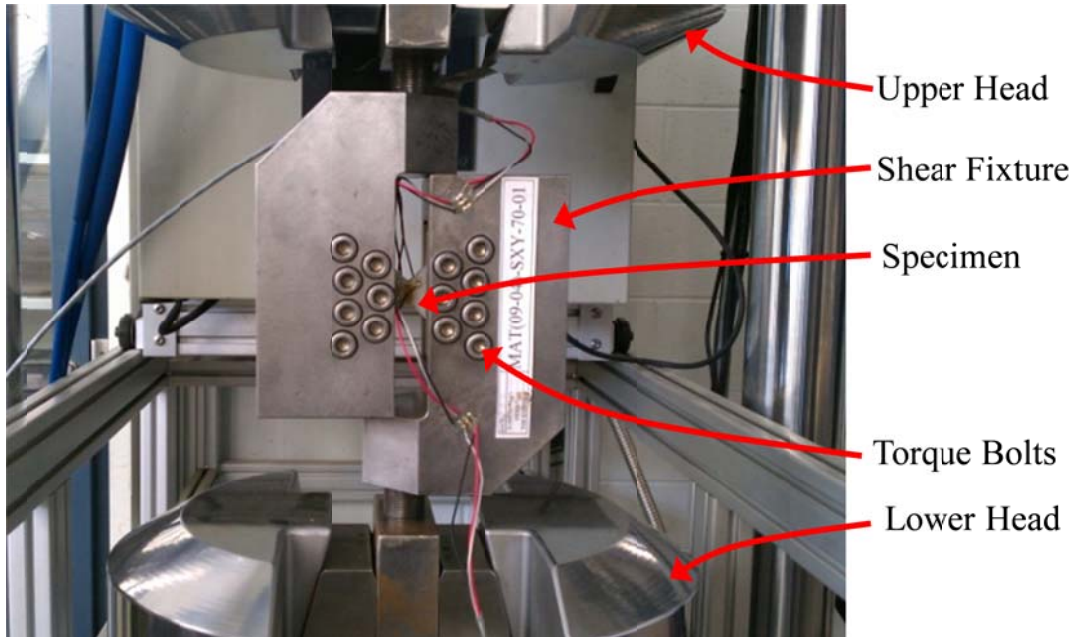


Figure 2.3-1: Test Setup for In-Plane Shear Test [9]

2.3.1 Specimen Geometry

Figure 2.3-2 shows the specimen dimensions which are a modification to the standard dimensions per ASTM D7078/D 7078M. The thickness of the specimen is equal to the nominal thickness of the composite plate when fabricated, ' t '. The reduced nominal notch length of 0.5 in. and the thickness were measured prior to testing to calculate accurate shear stresses at the notch.

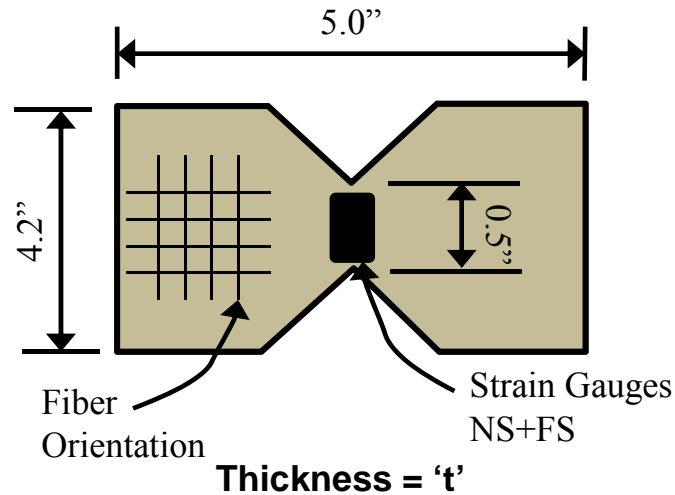


Figure 2.3-2: In-Plane Shear Test Specimen Dimensions and Strain Gauge Locations

2.3.2 Strain Gauge Setup

Two Vishay N2P-08-C032A-500/SP61 strain gauges are attached to measure the in-plane shear modulus of the material. One is located on each side of the specimen at the location identified in Figure 2.3-2. The average shear modulus calculated using the two gauges was reported for each specimen.

2.3.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Shear strength (S_{xy}) is calculated as:

$$S_{xy} = P_{\max} / A$$

P_{\max} is the maximum force at failure and A is the original cross-sectional area at the notch

- Shear stress at any load (τ_{xy}) is calculated as:

$$\tau_{xy} = P/A$$

- Shear modulus (G_{xy}) is calculated as:

$$G_{xy} = \Delta\tau / \Delta\gamma$$

- Where the change in shear stress $\Delta\tau$ and strain $\Delta\gamma$ readings are taken from the linear portion of the stress-strain curve which was typically between a load corresponding to 20% of the shear load capacity and 50% of the shear load capacity unless noted in Section 2.10.

2.4 Out-of-Plane Tension

The out-of-plane tensile test was conducted using ASTM D 7291/D 7291M [10] “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. This test determines the elastic and strength properties of the composite out-of-plane, meaning neither fiber orientation is parallel to the applied load. However, for Material 3-FY09, aramid fibers exist along the thickness which will be identified as the z axis. The test measures the through-thickness “flatwise” tensile strength, ST_z , and elastic modulus, E_z , of fiber reinforced polymer matrix composite materials.

Several iterations in the testing procedure were performed in order to finalize the out-of-plane tension testing. Initially, cylindrical specimens were provided to the research team. However, the research team could not find an adequate epoxy for bonding the specimen to metal adapters especially at high temperatures. Failure occurred at the bond between the specimen and the adapter which was either due to weaker epoxy or eccentricities in the test setup. Therefore, the research team purchased a special test fixture for performing out-of-plane tension testing in which the specimens were pinned to the test fixture. It was impractical to fabricate pin holes in the material tested because localized failures would occur due to bearing stresses. Therefore, it was more practical to add end tabs and connect the end tabs to the test fixtures via pins. Initially, metal (stainless steel) end tabs were used. However, issues still existed in the bond between the metal end tabs and the composite material. New end tabs were made of composite materials consisting of either the same material or a material composed of API SC-15 resin and S2-glass. The end tab material had fibers orientated parallel to the direction of loading. Therefore, failure would never occur in the end tab prior to failure in the material tested. However, bondline strength was still dependent on the material tested, the epoxy that was used, and the maximum temperature. More details on specimen fabrication are provided in Section 2.8.

During out-of-plane tension tests, it was critical to ensure that bending stresses were not developed due to misalignments or related issues. It was determined that using one universal joint causes a consistent but unacceptable failure mechanism. All specimens failed at the bottom near the epoxy line due to eccentricities that develop upon loading. Therefore, a fixture was obtained

that would allow pinned joints (free to rotate) at the top and bottom. Figure 2.4-1 shows the custom test fixture [11].

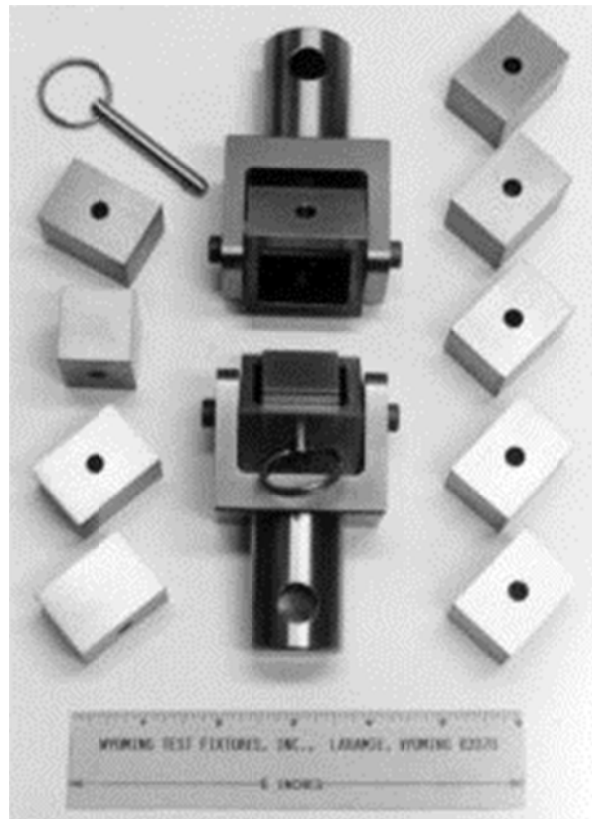


Figure 2.4-1: Test Fixture for Sandwich Panel Flatwise Tensile Test [11]

The machine used to perform the out-of-plane tension test is an Instron 8502A two post load frame with a universal joint. Figure 2.4-2 shows a picture of a specimen in the test fixture which is attached to the Instron test machine. A tensile force is applied normal to the plane of the composite laminate. The specimens were loaded to failure at a rate of 0.005 in/min.

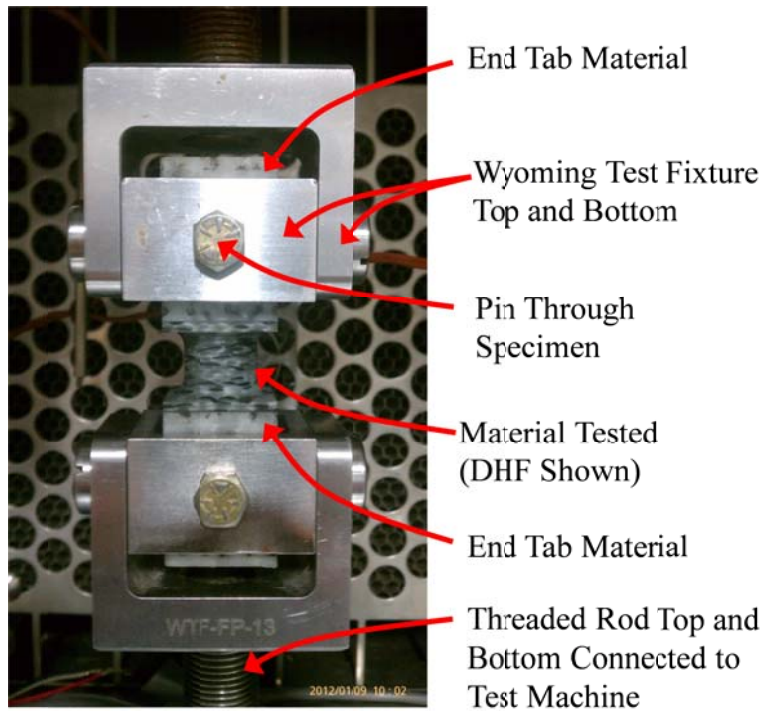


Figure 2.4-2: Test Setup for Out-of-Plane Tension Test [10]

2.4.1 Specimen Geometry

Figure 2.4-3 shows an illustration of the specimen dimensions (specimen not including end tabs) and the location of the strain gauges. Final dimensions varied for different materials tested at different temperatures. However, most of the specimens were spooled to a final diameter of 0.75 in the test area. The diameter was measured prior to every test to calculate average normal stresses. The final diameter had to ensure that failure occurred in the test area and not at the bond between the material being tested and the end tabs. The length of the specimen is equal to the nominal thickness of composite plate when fabricated, ' t '. The cross-sectional area where the material is attached to the end tab material (0.95 in. diameter shown) varied for the various materials tested. In some cases, this cross-section was square. Refer to Section 2.10.4 for more details.

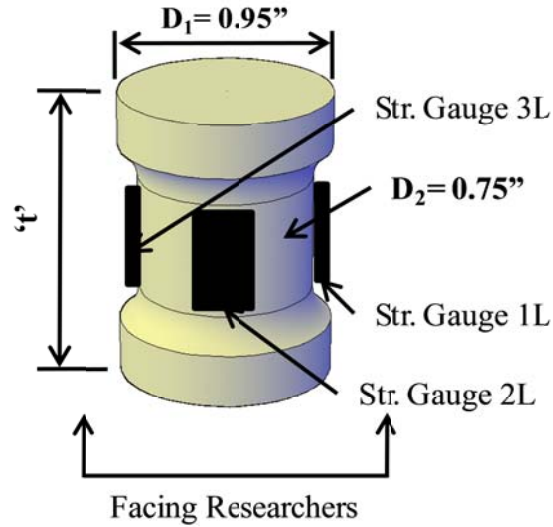


Figure 2.4-3: Out-of-Plane Tension Test Specimen Dimensions and Strain Gauge Locations

2.4.2 Strain Gauge Setup

Three Vishay CEA-06-125UW-350 strain gauges are fixed on the specimen parallel to the load (longitudinally) in the configuration shown in Figure 2.4-3. The gauges are placed 120° apart from each other around the cylindrical specimen. For each specimen, the elastic modulus was determined by averaging the results of the three strain gauges.

2.4.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Tensile strength (ST_z) is calculated as:

$$ST_z = P_{\max} / A$$

P_{\max} is the maximum force at failure and A is the cross-sectional area of the specimen.

- Longitudinal stress (σ_z) is calculated at any load level P as:

$$\sigma_z = P/A$$

- Modulus of elasticity (E_z) is calculated as:

$$E_z = \Delta\sigma_z / \Delta\epsilon_z$$

- Change in stress $\Delta\sigma_z$ and strain $\Delta\epsilon_z$ readings are taken from the linear portion of the σ - ϵ curve which was usually between a load corresponding to 20% of the axial load capacity and 50% of the axial load capacity unless noted in Section 2.10.

2.5 Out-of-Plane Compression

The out-of-plane compressive test is conducted using a modified version of ASTM D7291/D7291M [10] “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. A compressive force is applied to the specimen and dissimilar from the out-of-plane tension test, the specimens were cylinders and end tabs were not attached. The test measures the through-thickness “flatwise” compressive strength, meaning that the fiber plane is not oriented along the direction of load. As shown in Table 1.3-2, the test is used to determine the compressive strength, SC_z , and the out-of-plane compressive elastic modulus, EC_z .

A cylindrical specimen is set into a uniaxial test machine making direct contact with the upper and lower platens. Extra fixtures were not required for the compression test. The specimen is instrumented with strain gauges placed in the longitudinal direction and loaded to failure. The machine used to perform this test is a MTS 311 four post load frame with universal joint. Figure 2.5-1 shows a picture of a test setup (strain gauges not shown).

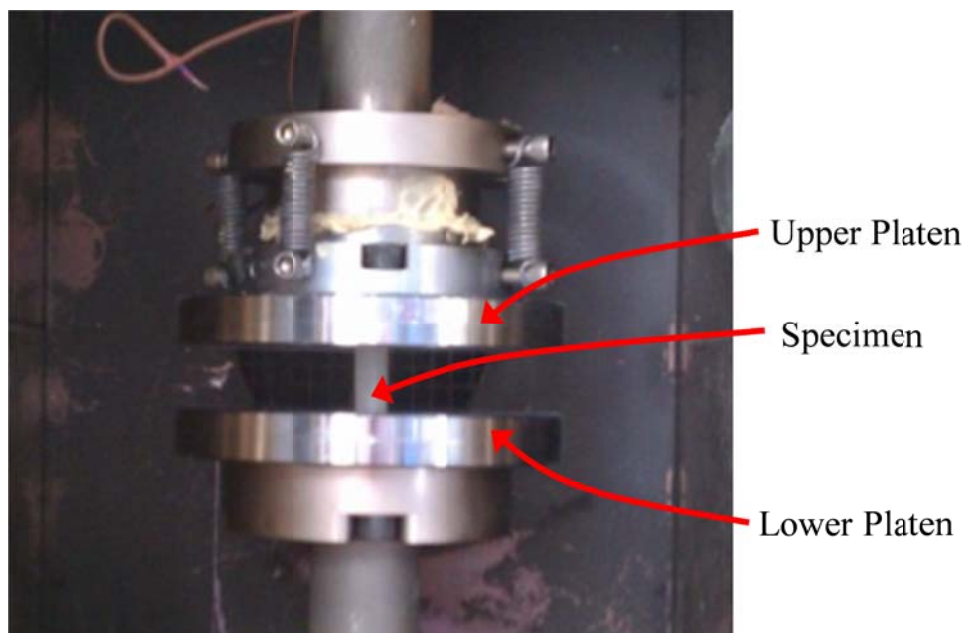


Figure 2.5-1: Test Setup for Out-of-Plane Compression

2.5.1 Specimen Geometry

Figure 2.5-2 shows an illustration of the test specimen dimensions and strain gauge locations. Initially, a diameter of 1.125 in. was used. However, localized failures occurred in the platens due to a high out-of-plane compressive strength of the material which was far higher than the in-plane compressive strength. In order to limit the maximum length/diameter ratio close to 2.0, the smallest diameter considered was 0.7 in. (max specimen length = 1.5 in.). However, applying strain gauges was difficult at this small diameter. A final diameter of 0.85 in. was chosen. The diameter was measured prior to every test to calculate average normal stresses.

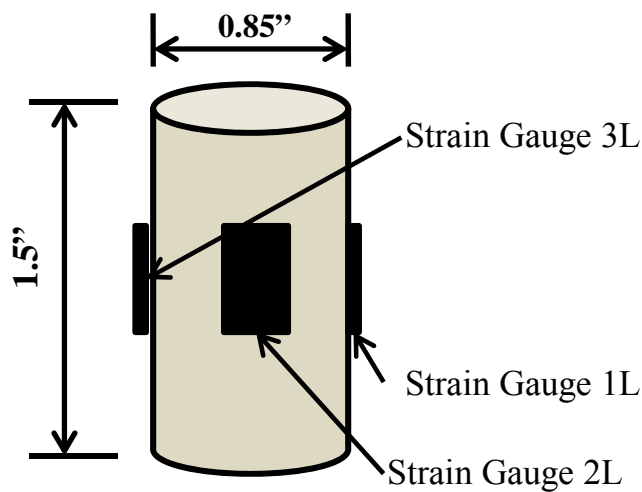


Figure 2.5-2: Out-of-Plane Compression Test Specimen Dimensions and Strain Gauges

2.5.2 Strain Gauge Setup

Three Vishay CEA-06-125UW-350 longitudinal strain gauges were placed on the cylindrical specimen 120° apart from each other with the configuration and nomenclature identified in Figure 2.5-2. The gauges were used to calculate the elastic modulus, EC_z . For each specimen, the average value of EC_z was determined using the results of the three strain gauges is used.

2.5.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Compressive strength(SC_z) is calculated as:

$$SC_z = P_{\max} / A$$

P_{\max} is the maximum force at failure and A is the cross-sectional area of the specimen.

- Longitudinal stress (σ_z) is calculated at any load level P as:

$$\sigma_z = P/A$$

- Modulus of elasticity (EC_z) is calculated as:

$$EC_z = \Delta\sigma_z / \Delta\epsilon_z$$

- Where change in stress $\Delta\sigma$ and strain $\Delta\epsilon$ readings are taken from the linear portion of the stress-strain curve which was usually between a load corresponding to 20% of the shear load capacity and 50% of the shear load capacity unless noted in Section 2.10.

2.6 Out-of-Plane Shear

The out-of-plane shear test is conducted using ASTM D 5379/ D 5379M [12] “Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method”. Out-of-plane refers to the fiber orientation with respect to the test. Fibers are oriented along the width and the ‘thickness’ of the specimen. Note that the thickness of the specimen is not along the same orientation as the thickness of the composite plate. As shown in Table 1.3-2, the out-of-plane shear test measures the out-of-plane shear modulus, G_{xz} or G_{yz} , and the out-of-plane shear strength, S_{xz} or S_{yz} .

In order to accommodate the fixture used to perform the test, the specimens were required to have a minimum total length of 3 in. For this test, the length of the specimen is equal to the thickness of the material which ranges from 0.75 in. to 1.5 in. Therefore, end tabs were required on either side of the specimen in order to extend the overall length of the specimen to a minimum length of 3 in. The overall lengths were often greater than 3 in. Notches were then fabricated in the out-of-plane shear specimens. More details about fabricating the out-of-plane shear specimens are provided in Section 2.8.

Figure 2.6-1 shows a picture of an out-of-plane shear specimen within the test fixture. The machine used to perform this test is an Instron 8502A two post load frame.

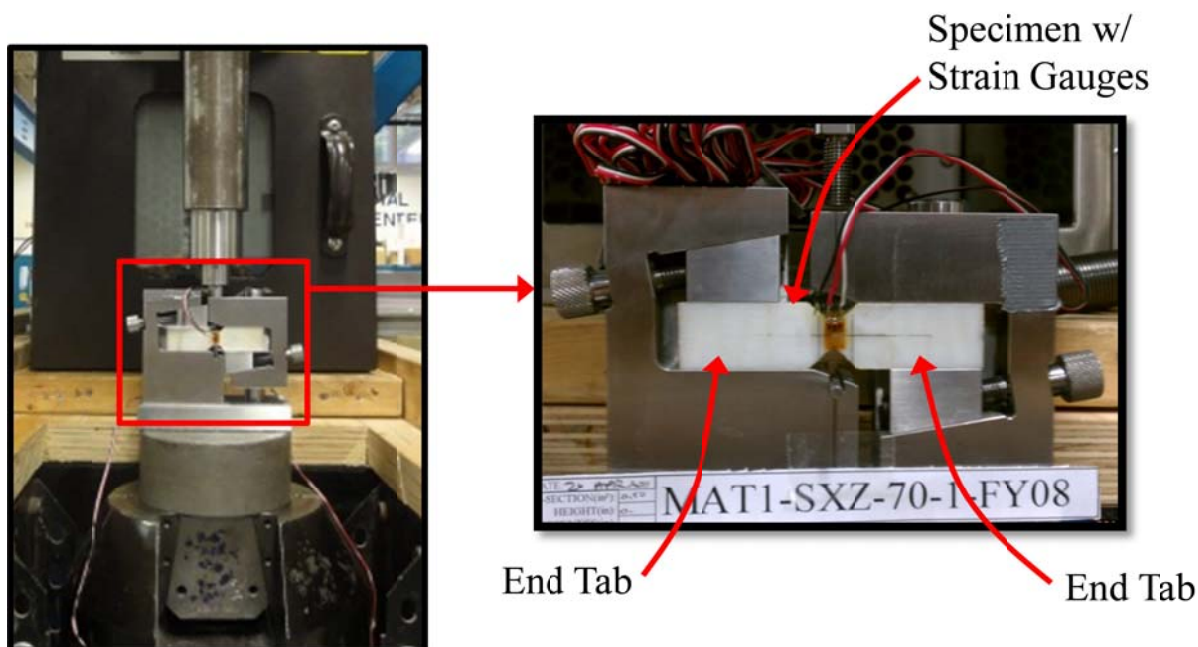


Figure 2.6-1: Test Setup for Out-of-Plane Shear [12]

2.6.1 Specimen Geometry

Figure 2.6-2 shows an illustration of the test specimen dimensions and strain gauge locations. As mentioned but not shown in Figure 2.6-2, the material tested was adhesively bonded to end tabs fabricated from either the same material or other similar composite materials. The thickness of the specimen was 0.5 in., the width of the specimen was 0.75 in., and the length of the specimen was equal to the nominal thickness of the composite plate when fabricated, ' t '. The specimen width was reduced to a notch width of 0.3 in. Shear stress was computed using the cross-sectional area associated with this notch width. The thickness and the notch width were measured prior to every test to calculate the average shear stresses.

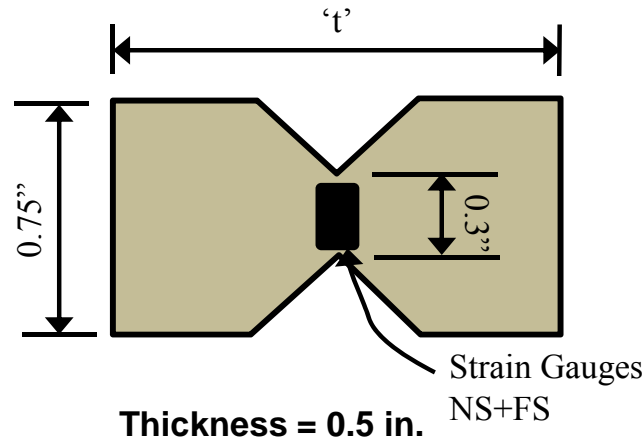


Figure 2.6-2: Out-of-Plane Shear Test Specimen Dimensions and Strain Gauge Locations

2.6.2 Strain Gauge Setup

Two Vishay CEA-06-062UV-350 strain gauges were attached on each side of the specimen. These strain gauges measure shear strain and were therefore used to determine the out-of-plane shear modulus of the material. The average shear modulus calculated using the results of each strain gauge was reported.

2.6.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- Shear strength (S_{xz} or S_{yz}) is calculated as:

$$S_{xz} = P_{\max} / A$$

- P_{\max} is maximum force at failure and A is the cross-sectional area at the smallest cross-section
- Shear stress at any load (τ_{xz} or τ_{yz}) is calculated as:

$$\tau_{xz} = P/A$$

- Shear modulus (G_{xz} or G_{yz}) is calculated as:

$$G_{xz} = \Delta\tau / \Delta\gamma$$

- Where change in shear stress $\Delta\tau$ and strain $\Delta\gamma$ readings are taken from the linear portion of the stress-strain curve which was usually between a load corresponding to 20% of the shear load capacity and 50% of the shear load capacity unless noted in Section 2.10.

2.7 Out-of-Plane Poisson

The out-of-plane Poisson's ratio test is conducted using a modified version of ASTM D 7291/D 7291M [10] "Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material". Instead of using a cylindrical specimen, a block specimen is used to perform the test since attaching lateral gauges to cylindrical specimens will not assist in directly computing the Poisson's ratio. The test is performed in the same manner as the out-of-plane tension test (see Section 2.4). As shown in Table 1.3-2, the out-of-plane Poisson's ratio test is used to calculate the Poisson's ratio, ν_{xz} or ν_{yz} .

End tabs were bonded to the material for conducting the out-of-plane Poisson tests. Since only elastic properties were measured, it was not required to reach the tensile strength. The test was considered acceptable if the stress reached 50% of the maximum stress prior to bondline failure. Therefore, the elastic property, Poisson's ratio, could be computed using data corresponding to 20% and 50% of the maximum axial loads. The maximum stress was determined using the maximum stress obtained from the out-of-plane tension testing when the same material was subjected to tensile stress at the same temperature.

The machine used to perform this test is the Instron 8502A two post load frame with a universal joint. Figure 2.7-1 shows a picture of a specimen in the Instron test load frame. A tensile force is applied normal to the plane of the composite laminate. As shown in Figure 2.7-1, the specimens are bonded to end tabs that are attached to the test fixture discussed in Section 2.4.

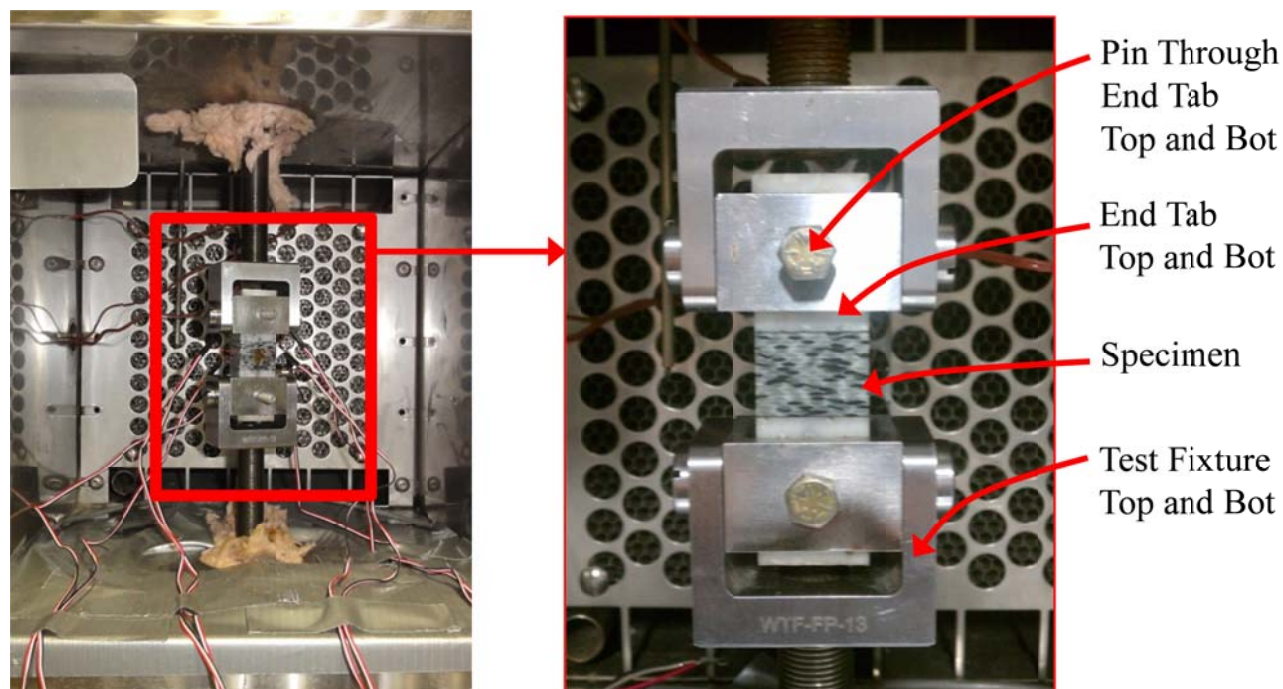


Figure 2.7-1: Test Setup for Out-of-Plane Poisson's Tests

2.7.1 Specimen Geometry

Figure 2.7-2 shows the nominal dimensions of the out-of-plane Poisson specimens. The fabrication of the test specimen is discussed in Section 2.8. The material tested had cross-sectional dimensions of 1 in. x 1 in. and a length equal the nominal thickness of the composite plate which ranged from 0.75 in. to 1.5 in. The dimensions (shown as 1 in. and 1 in.) were measured prior to each test. The material tested was adhesively bonded to end tabs (not shown Figure 2.7-2) fabricated from either the same material or other similar composite materials.

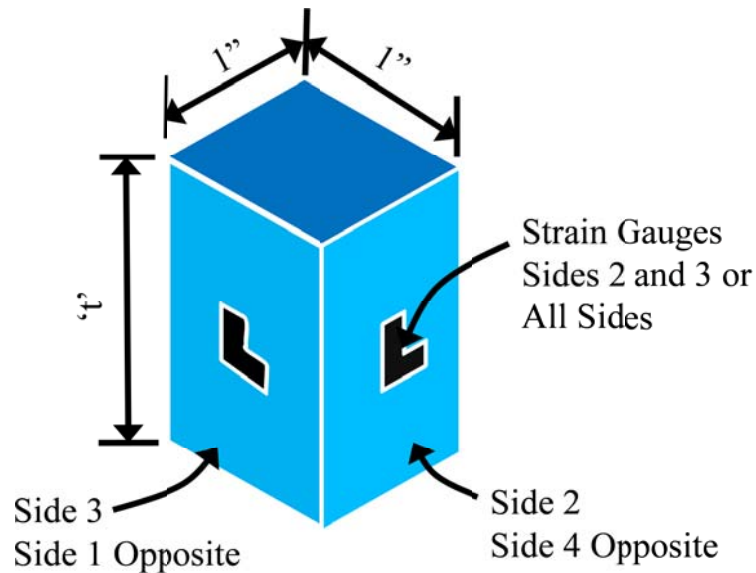


Figure 2.7-2: Out-of-Plane Poisson Specimen Dimensions and Strain Gauge Locations

2.7.2 Strain Gauge Setup

C2A-06-125LT-350 strain gauges are used to measure both the transverse strain (ϵ_t) and the longitudinal strain (ϵ_l). Two are placed on adjacent faces of the specimen upon testing (i.e. 4 strain measurements total). An average value of the Poisson ratio from the two sides is recorded. Note for the DHF material, strain gauges were placed on all four sides of the specimen as discussed in Section 2.10.

2.7.3 Calculation of Measured Properties

The following is a summary of the calculations used to measure the material properties:

- The Poisson's ratio (ν_{xz} or ν_{yz}) is calculated as:

$$\nu_{xz} = - \Delta \epsilon_t / \Delta \epsilon_l$$
- Where $\Delta \epsilon_t$ is the transverse strain and $\Delta \epsilon_l$ is the longitudinal strain, taken from the linear portion of the σ - ϵ curve which was usually between a load corresponding to 20% of the axial load capacity and 50% of the axial load capacity unless noted in Section 2.10.

2.8 Fabrication of Out-of-Plane Specimens

As mentioned in Sections 2.4, 2.6, and 2.7, out-of-plane tension, shear, and Poisson specimens were adhesively bonded to end tabs made of either the same material or similar composite materials. To fabricate these specimens, three composite blocks were epoxied together prior to fabricating the completed specimens. The center block was made of the material tested (test block) and the top and bottom blocks became end tabs. Once epoxied together, these combined blocks became multiple specimens. Figure 2.8-1 shows a picture of three blocks that were later epoxied together and fabricated into test specimens. When received, the ‘test block’ was 12 in. x 1.5 in. x ‘ t ’ where ‘ t ’ is the nominal thickness of the composite plate. The two ‘end tab blocks’ were 12 in. x 1.5 in. x 1.5 in. The research team reduced these dimensions as required to accommodate the test performed. However, the nominal thickness ‘ t ’ was never reduced.



Figure 2.8-1: Individual 12 in. Blocks Provided by TARDEC to Research Team

Prior to bonding the blocks together, the individual blocks were squared. All corners of the blocks were specified to have 90° angles using a CNC mill. Custom polycrystalline diamond (PCD) indexable cutting inserts were used to mill the material to the desired surface profile. The

PCD cutters enhance the life of the cutting tools when cutting glass-reinforced composite materials. All CNC milling procedures were performed using PCD cutters.

Once the individual blocks were squared, they were epoxied together. The research team attempted to use several different epoxies during the acceptance testing phase of the project and for the testing of further materials. Certain epoxies performed more favorably for different composite materials and in different temperature conditions. This is discussed in more detail in Section 2.8.1. It was determined that the best epoxy for several applications was a two part epoxy produced by 3M (Designation DP420, Black) with 0.25-0.50 mm diameter glass beads added to the epoxy. Prior to and during curing, the specimens were clamped together as shown in Figure 2.8-2.



Figure 2.8-2: Condition during Curing with Specimens Clamped Together

The epoxy was cured by means of oven heating for 60 minutes at 60 °C. The ‘bonded blocks’ were left at ambient temperatures for a period of 24 hours prior to further fabrication efforts. Then, the bonded block was squared using the same CNC mill that was used to square individual blocks. Figure 2.8-3a shows a picture of a bonded block in the CNC mill prior to squaring and Figure 2.8.3b shows another block after squaring.

a) Prior to Squaring Specimen



b) After Squaring Specimen

**Figure 2.8-3: Bonded Block in CNC Mill Prior to (a) and After (b) Squaring all Sides**

The 12 in. bonded blocks were separated in half (6 in. long) using a horizontal band saw. Further fabrication efforts were dependent on the individual out-of-plane test that was performed on the material. Therefore, prior to individual fabrication efforts for a specific test, the bonded

blocks were approximately 6 in. long, 1.5 in. thick, and had a width equal to 3 in. plus the nominal thickness of the composite plate.

The blocks that were used to fabricate out-of-plane tension and out-of-plane Poisson specimens were cut and grinded down to a thickness of 1 in. using a surface grinder with custom electro plated diamond coated wheels as shown in Figure 2.8-4.



Figure 2.8-4: Blocks Reduced to Thickness of 1 in. using Surface Grinder

The 6 in. long by 1 in. thick blocks were separated into five pieces, each with a length of 1.05 in. using the horizontal band saw. These individual pieces were fabricated into five individual specimens. Figure 2.8-5 shows a piece saw cut from the 6 in. long block. Once the individual pieces were removed, the 1.05 in. dimension was further reduced to 1 in. using the surface grinder (see Figure 2.8-4). The reduced block has a width equal to 1 in., a thickness equal to 1 in., and a length equal to 3 in. plus the nominal thickness of the composite plate.



Figure 2.8-5: Composites Saw Cut into 1 in. Thick by 1.05 in. Wide Blocks

During the actual material testing, specimens used for the out-of-plane tension and out-of-plane Poisson's testing were connected to a test fixture using pins. Therefore, the specimens were placed into a Bridgeport mill and 0.28 in. diameter holes were drilled in the end tabs to accommodate the pin connections. This procedure is shown in Figure 2.8-6. This completed the general specimen fabrication efforts required to perform the out-of-plane Poisson testing. Specific modifications were required for some materials and will be discussed in Section 2.10. More fabrication work was required for the out-of-plane tensile specimens.

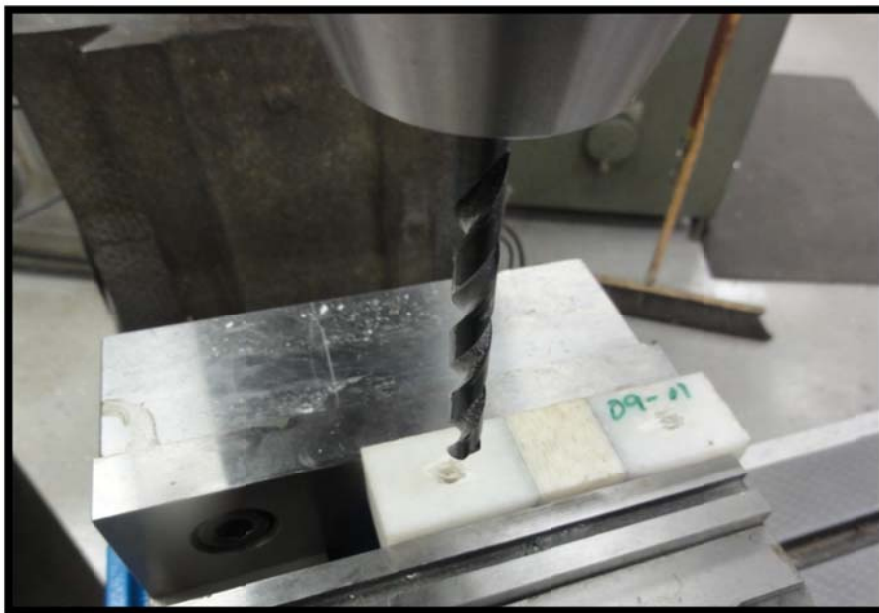


Figure 2.8-6: Holes Drilled in End Tabs to Connect to Test Fixture using Bridgeport Mill

To complete the fabrication of the out-of-plane tension specimens, center drill holes were located at the top and bottom face of the specimen end tabs using the Bridgeport Mill. The holes allow the block to be mounted on electro precision centers. The spinning center was placed on the surface grinder. The mid-section of the material tested was spooled using a custom profile diamond coated grinding wheel. Figure 2.8-7 shows the process that was used to spool the specimen. This completed the general fabrication procedure for the out-of-plane tension specimens. Specific modifications were required for some materials and will be discussed in Section 2.10.

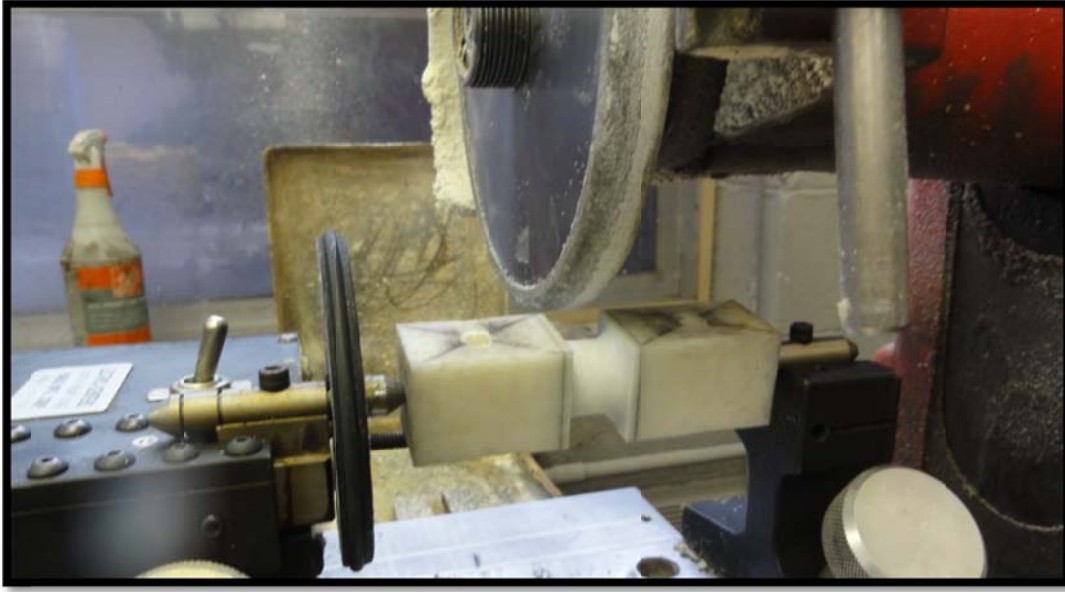


Figure 2.8-7: Spooling of Out-of-Plane Tension Specimens

Specific fabrication procedures for the out-of-plane shear specimens began after fabricating the 6 in. long bonded blocks. The blocks were cut and grinded down to a thickness of 0.8 in. using the surface grinder shown in Figure 2.8-4 with custom electro plated diamond coated wheels. The 6 in. long by 0.8 in. thick blocks were placed on a sine plate which mounted on a Bridgeport Mill in order to machine the V-notch. This process is shown in Figures 2.8-8 and 2.8-9.

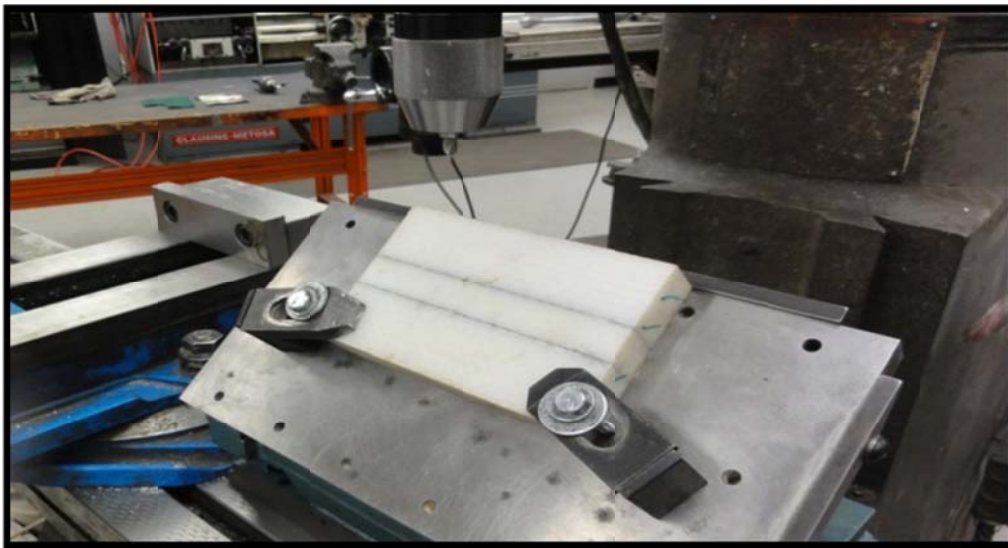


Figure 2.8-8: Six inch Long Specimens Placed on Bridgeport Mill to Machine V-Notch



Figure 2.8-9: V-Notch Fabricated Through 6 in. Long Block Specimens

The parts were cut and grinded to final dimensions of 0.75 in. wide x 0.5 in. thick x 3.0 in. long (total) using a horizontal saw and surface grinder. Figures 2.8-10 to 2.8-15 show two completed out-of-plane Poisson specimens, two completed out-of-plane tension specimens, and two completed out-of-plane shear specimens.

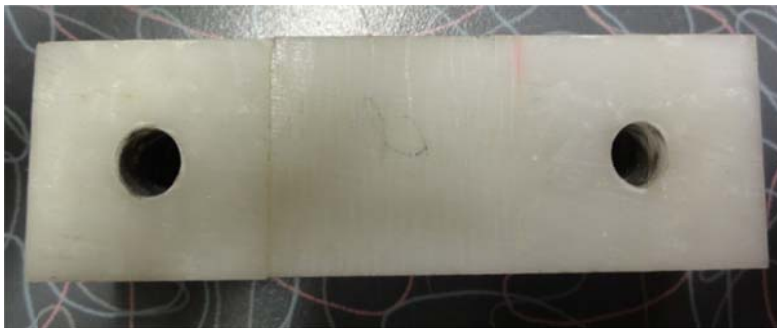


Figure 2.8-10: Completed Out-of-Plane Poisson Specimen

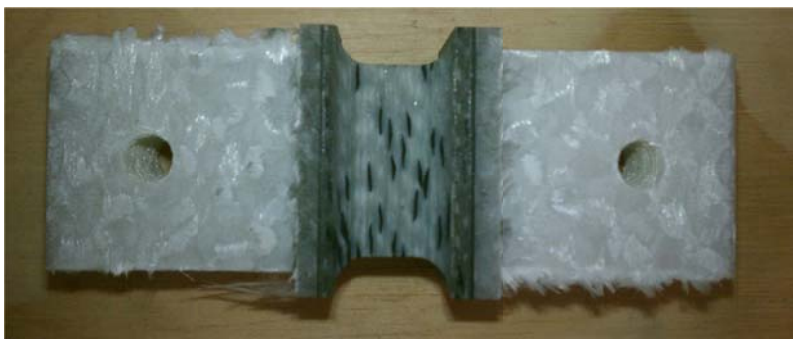


Figure 2.8-11: Completed Out-of-Plane Poisson Specimen with Inc. Surface Area at Bond



Figure 2.8-12: Completed Out-of-Plane Tension Specimen



Figure 2.8-13: Completed Out-of-Plane Tension Specimen with Inc. Surface Area at Bond

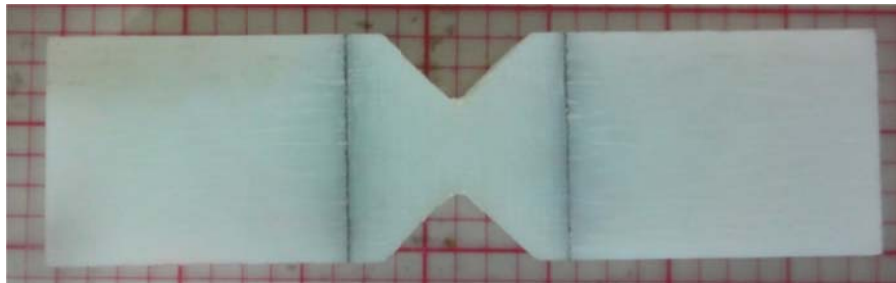


Figure 2.8-14: Completed Out-of-Plane Shear Specimen



Figure 2.8-15: Completed Out-of-Plane Shear Specimen

2.8.1 Epoxies

During the acceptance testing and during the material testing for select materials, trial tests were performed in order to determine epoxies that would be capable of attaching specimens to the initial metal end tabs and later, the end tabs made of composite materials. This section summarizes which epoxies were favorable in providing the adequate bond strength and other epoxies that were not adequate. This section is meant to serve for future research in selection of appropriate epoxies.

The adhesives that were tested were all two part epoxy systems provided by West Systems Inc. Some examples are provided below.

- 105/205 resin and hardener
- G-flex
- Six10

During the acceptance testing, the research team concluded that West Systems Six10 epoxy was the best candidate for performing out-of-plane testing. This epoxy was used throughout the acceptance testing and therefore was used to verify all testing procedures.

The out-of-plane tensile strength of the actual materials was found to be higher than the out-of-plane tensile strength of the material used to perform the acceptance testing. Therefore, more studies were required to determine adequate adhesives for performing the tests. Extensive research was performed to find an adhesive that was capable of adhering the composite material to the stainless steel end-tab to a stress of at least 3,000 psi. However, the bonding of dissimilar materials was found to be a significant issue especially at elevated temperatures. Table 2.8-1 provides a list of adhesives tested in this project and is included in this report for reference in future research projects. The adhesive that out performed all others was 3M Scotch-Weld DP420 Black for both bonding to metal end tabs and for bonding to composite end tabs.

Table 2.8-1: Adhesives used to Bond Material Tested to End Tabs

| Manufacturer | Product Name | Adhesive Class |
|---------------------|---------------------|-----------------------|
| West System | Six10 | Epoxy |
| West System | G-Flex | Epoxy |
| West System | 205 / 204 | Epoxy |
| Lord | 606 | 2-Part Acrylic |
| Lord | 406 | Methyl Methacrylate |
| Armstrong | C-1 / A | Epoxy |
| Araldite | 2014 | Epoxy |
| Devcon | Plastic Welder | Epoxy |
| ResinLab | EP1238 | Epoxy |
| 3M | EC2216 | Epoxy |
| 3M | DP420 | Epoxy |
| Extreme Adhesives | EXT 300 | Methyl Methacrylate |
| Extreme Adhesives | SS305 | Metal Bonder |
| Extreme Adhesives | 766 | Cyanoacrylate |
| Vishay | M-Bond 200 | Cyanoacrylate |

2.9 Environmental Chambers

In collaboration with TARDEC, the research team at LTU agreed that for each material and each test type, properties will be measured at three different temperatures. The testing procedure had to accommodate the three chosen temperatures of -40°F, 70°F (ambient), and 140°F.

Two environmental chambers were obtained to perform the testing, one for each load frame. During the acceptance testing, researchers were responsible for obtaining the chambers, constructing frames for the chambers, and determine how the specimens will fit in the chambers.

A larger environmental chamber is used for the testing conducted with the MTS machine. Figure 2.9-1 shows a picture of this chamber identifying the key components. A smaller environmental chamber is used for testing conducted with the Instron machine. Figure 2.9-2 shows a picture of this chamber identifying the key components.

Each environmental chamber has holes on the top and bottom that allows either the specimen or fixture attachments to pass through into the chamber. For the in-plane tensile test, a portion of the specimen is not located in the chamber upon testing. For all of the other tests, the entire

specimen is within the chamber during the test. The research team designed two test chamber frames that allow the chamber to slide in and out of the test machines.

In order to perform the environmental tests at cold temperatures, nitrogen tanks were purchased along with hoses that attach to the environmental chamber. A picture of a typical nitrogen tank and the attached hoses is shown in Figure 2.9-3.

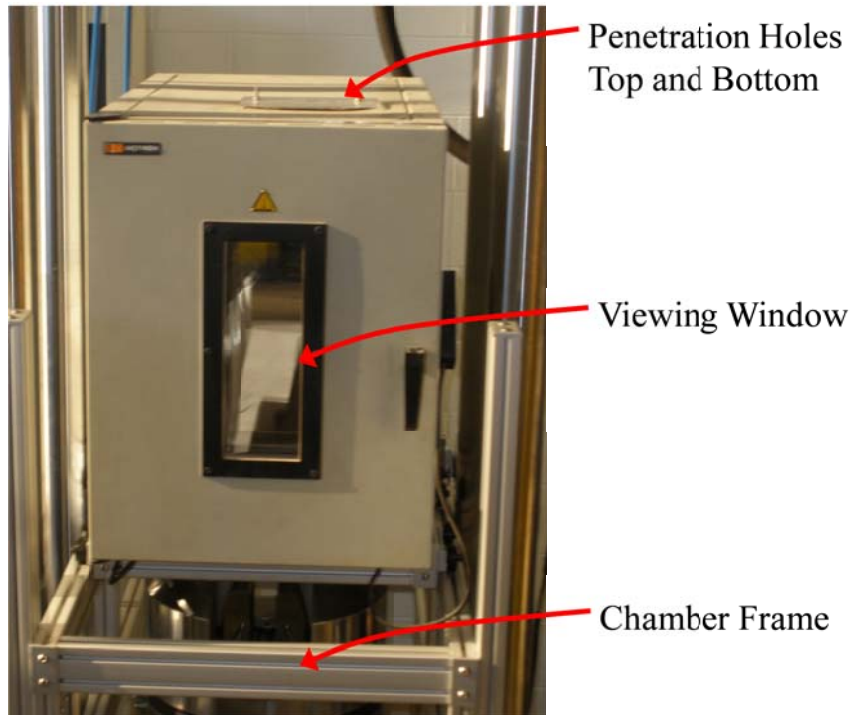


Figure 2.9-1: Large Environmental Chamber used with MTS Machine

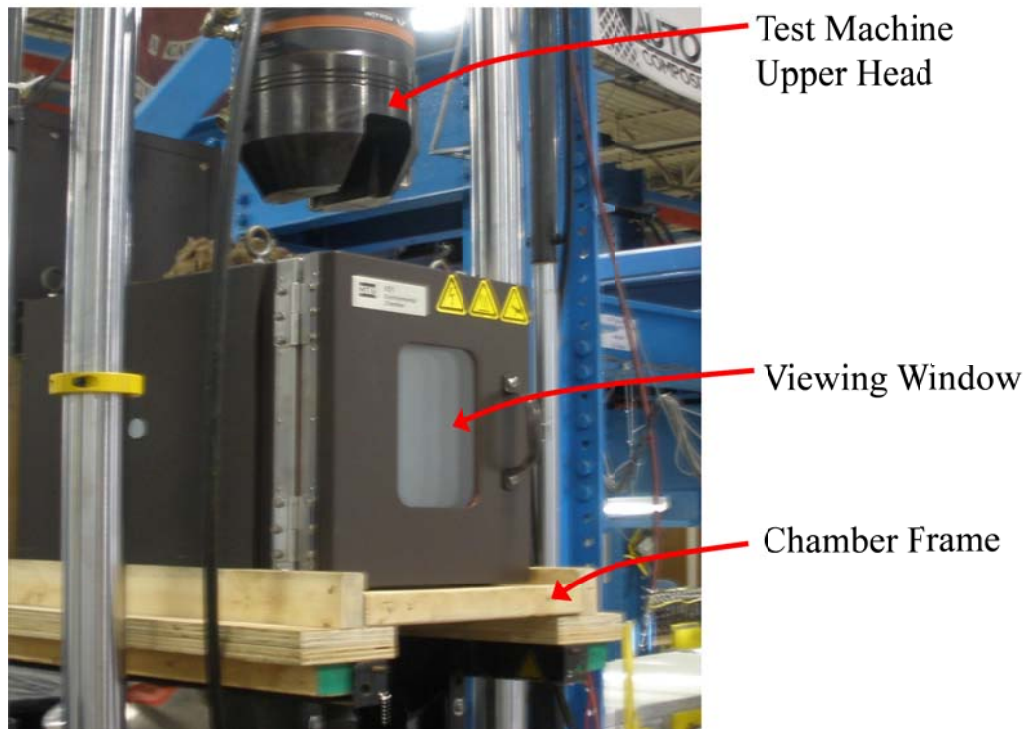


Figure 2.9-2: Small Environmental Chamber with Instron Machine



Figure 2.9-3: Nitrogen Gas Tank and Attached Hose

Thermal studies were conducted to determine the time required to subject the entire specimen (i.e. through the thickness) to the target temperature. The research team used the 1.5 in. thick shear specimens to conduct the tests. This is the thickest specimen tested and the results are conservative for other specimen thickness. The research team drilled into the specimen from both ends and inserted two thermocouples towards the center of the specimen. The thermocouples were coated with mixed epoxy and drill shavings from the specimen. An additional epoxy-shaving mix was inserted into the hole to fill. The specimen was placed into the environmental chamber. Prior to conducting each test, the specimen temperature was stabilized at 70°F.

2.9.1 Thermal Conductivity Test: Results for -40°F

Tests were conducted to determine the time required for the specimen to reach -40°F throughout the thickness. Initially, the research team conducted the -40°F temperature test by setting the air temperature to -40°F. However, it was found that the core temperature of the specimen would not reach -40°F until after a long period of time. The first test was discarded from the results. To account for this, the air temperature of the chamber was decreased to -49°F which resulted in core temperatures of -40°F. The results indicate that specifying an air temperature in the chamber as -49°F allowed the core temperature to reach the desired temperature of -40°F faster. In addition, the core temperature stabilizes for a long enough period of time such that a test can be conducted at the specified temperature. The results of Tests 2-5 are summarized in Table 2.9-1. Typical time-temperature curves are shown in Figures 2.9-4 and 2.9-5. From the results, it was determined to allow a soak time of 40 minutes for the 1.5 in. specimens and 30 minutes for other specimens with a smaller thickness.

Table 2.9-1: Summary of Thermal Studies to Achieve -40°F Throughout Thickness

| Test Number | Chamber Temperature (°F) | Specimen Soak Time (min) |
|--------------------|---------------------------------|---------------------------------|
| 2 | -49 | 38 |
| 3 | -49 | 33 |
| 4 | -49 | 40 |
| 5 | -49 | 30 |
| 6 | -49 | 30 |
| Average | - | 34 |

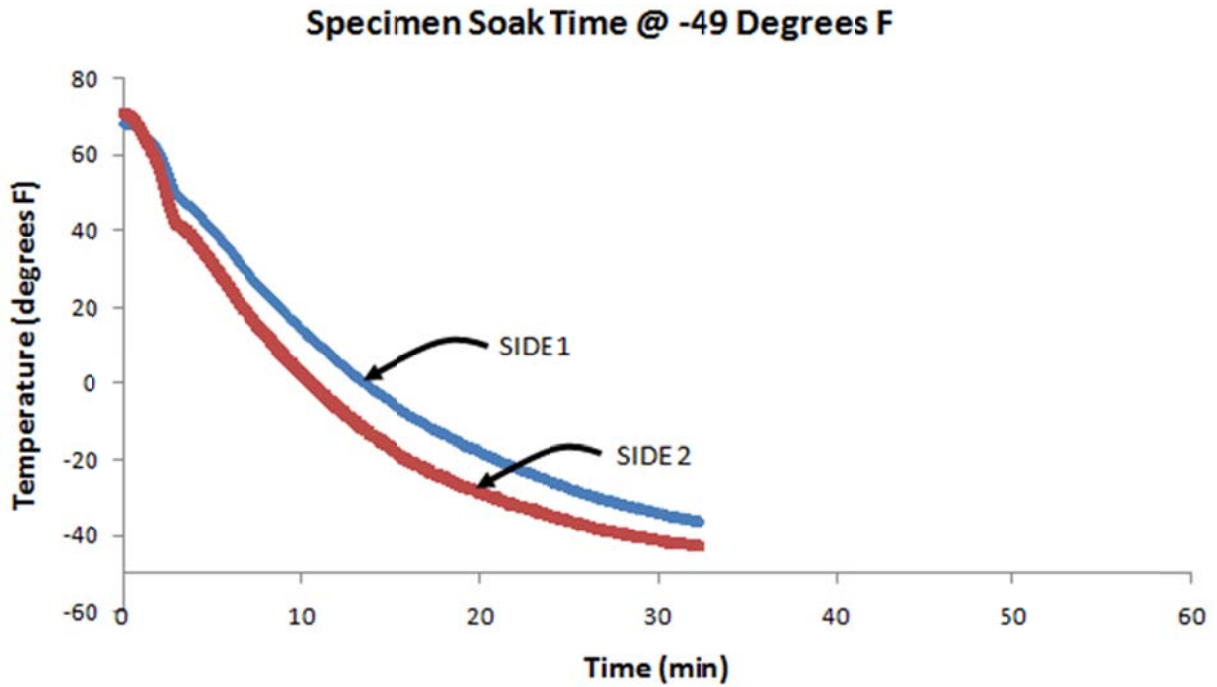


Figure 2.9-4: Time-Temperature Results for Test 3 in Table 2.9-1

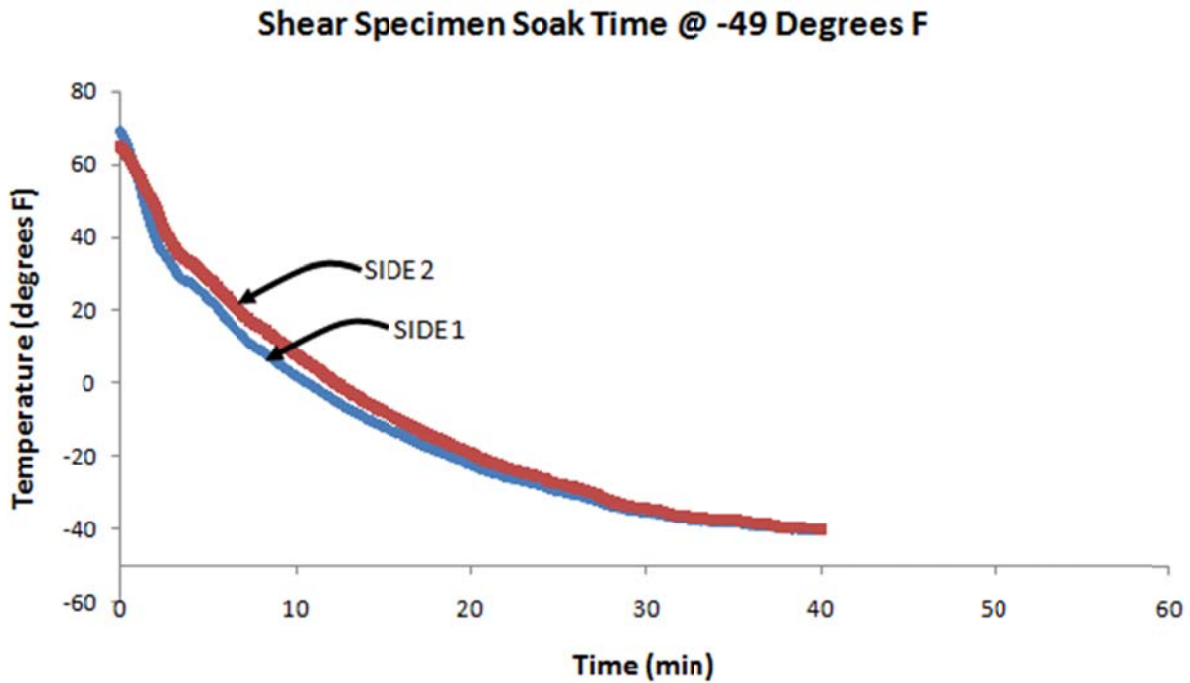


Figure 2.9-5: Time-Temperature Results for Test 4 in Table 2.9-1

2.9.2 Thermal Conductivity Test: Results for 140°F

Tests were conducted to determine the time required for the specimen to reach 140°F throughout the entire thickness. The first two tests at 140°F were conducted by setting the air temperature of the chamber to 140°F. However, the core temperatures of the specimen would not reach the air temperature. Therefore, the air temperature of the chamber was increased to 149°F which proved to be sufficient. The results of Tests 3-5 are shown in Table 2.9-2. Typical time-temperature data is shown in Figures 2.9-6 and 2.9-7. The results of these tests clearly indicate that 30 minutes is a sufficient soak time for all specimens.

Table 2.9-2: Summary of Thermal Studies to Achieve 140°F Throughout Thickness

| Test Number | Chamber Temperature (°F) | Specimen Soak Time (min) |
|-------------|--------------------------|--------------------------|
| 3 | 149 | 30 |
| 4 | 149 | 30 |
| 5 | 149 | 30 |
| Average | - | 30 |

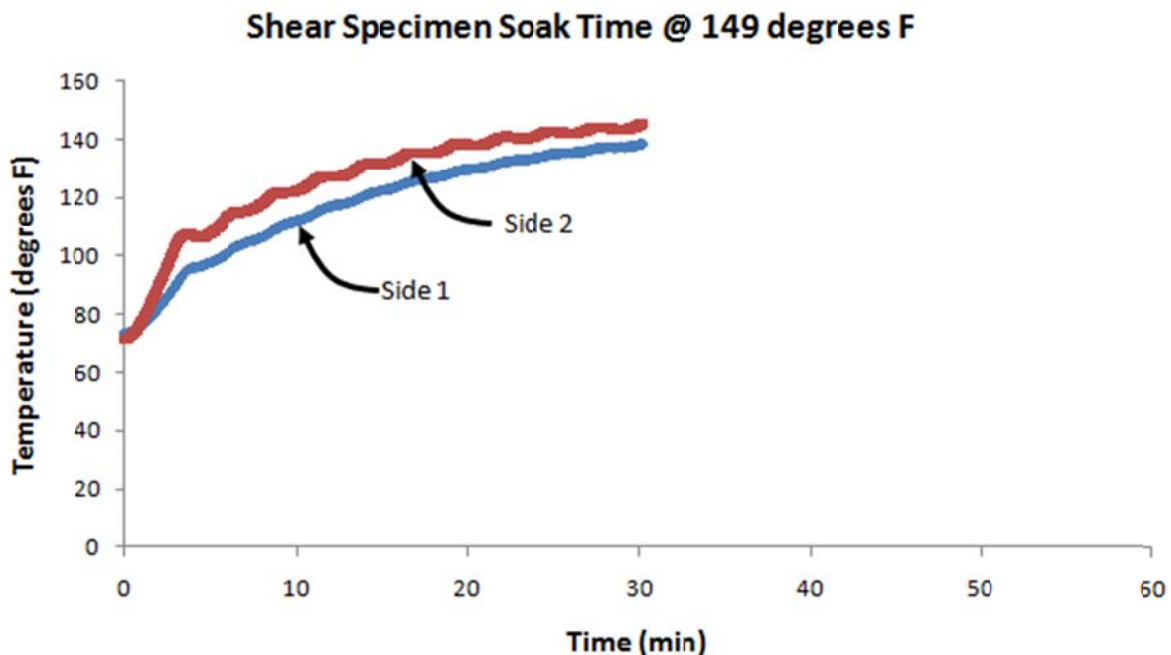


Figure 2.9-6: Time-Temperature Results for Test 3 in Table 2.9-2

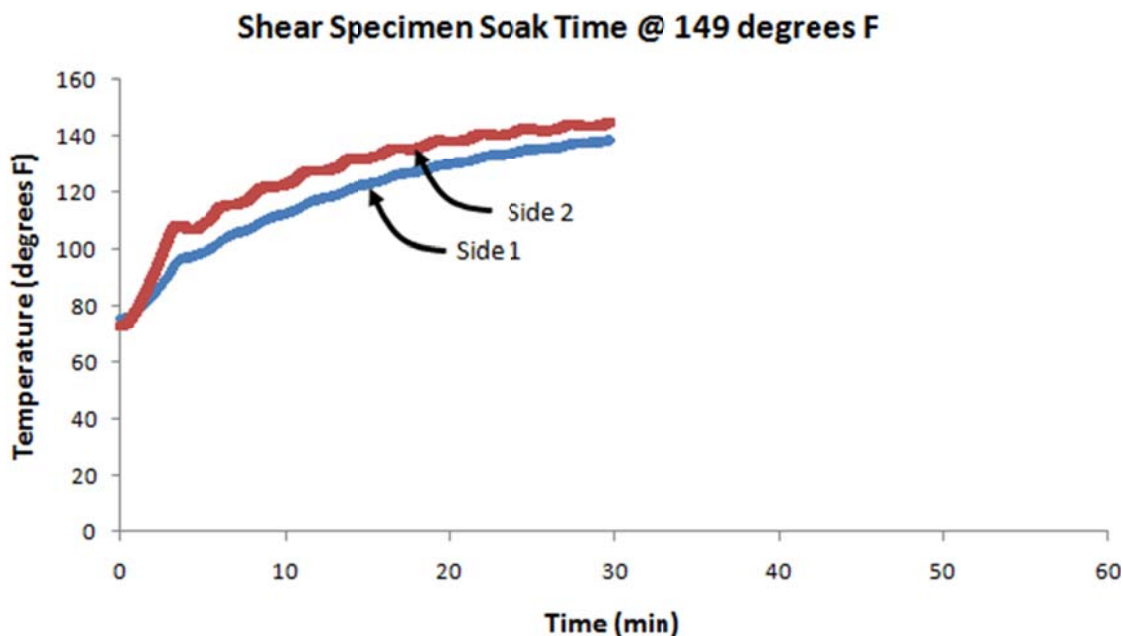


Figure 2.9-7: Time-Temperature Results for Test 4 in Table 2.9-2

2.10 Modifications to Testing Procedure and Other Notes

This section summarizes all of the changes that were made to the testing procedure necessary for select materials. This section is organized such that each sub-section represents all changes for a specific test type. These changes are only applicable for final testing results and not for acceptance testing.

2.10.1 In-Plane Tension Test

The in-plane tension tests of Material 2-FY08, Material 1-FY09, Material 2-FY09, Material 4-FY09, and Material 5-FY09 were all performed as summarized in Section 2.1. No significant deviations to the testing procedure were required.

The in-plane tension tests of Material 1-FY08 were performed as discussed in Section 2.1 with some modifications to the strain gauge configuration. Vishay N2A-06-20CBW-350 gauges were attached to one or two sides of the specimen and Vishay C2A-06-125LT-350 gauges were attached to each other side. For all other in-plane tension tests, one Vishay N2A-06-20CBW-350 gauge

was used on one side and three Vishay C2A-06-125LT-350 gauges were used on the other three sides as discussed in Section 2.1.

The specimen geometry for the Material 3-FY09 in-plane tension specimens was critical due to a unique failure mode in comparison to most composite materials tested in this research. Failure was localized at the smallest cross-sectional area. Figure 2.10-1 shows an example of the failure of Specimen MAT3-TX-3-140-FY09.



Figure 2.100-1 Localized Failure of Specimen MAT3-TX-3-140-FY09

To control the location of failure and ensure accurate strain gauge readings, the specimen thickness was reduced using a CNC mill. The thickness was reduced from a nominal value of 0.5 in. to a nominal value of 0.4 in. along a 6 in. length. The actual thickness varied from 0.33 in. to 0.37 in. Figure 2.10-2 shows the nominal dimensions of the Material 3-FY09 in-plane tension specimens. All failures occurred within the 6 in. length with the reduced thickness.

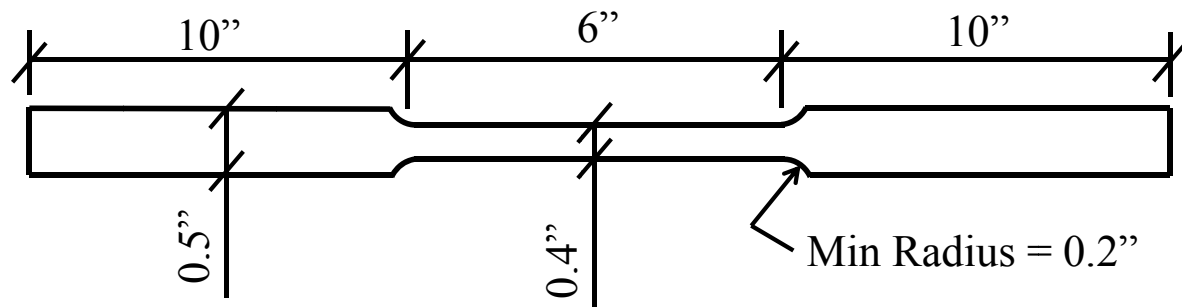


Figure 2.100-2: Final Specimen Geometry for Material 3-FY09 In-Plane Tension Specimens

For Material 3-FY09, elastic properties were not always computed at a range that corresponded to 20% - 50% of the axial load capacity since the material exhibited elastic behavior over shorter ranges as evident from the stress-strain curves in Appendix F. This was more evident when observing the transverse strains. At -40°F, the elastic modulus was computed at a range that corresponded to 10% - 35% of the axial load capacity. For temperatures of -40°F and 140°F, the Poisson's ratio was computed over a range that corresponded to 0% - 10% of the axial load capacity. For a temperature of 70°F, the Poisson's ratio was computed over a range that corresponded to 0% - 20% of the axial load capacity.

The in-plane tension specimen geometry was also critical for Material 6-FY09. Some specimens that were initially obtained by the research team were deemed inadequate due to localized failures. Therefore, more specimens were requested and received by the research team at a later date. Specific and accurate specimen geometry was required due to a unique failure mode in comparison to materials with S2-glass. Failure was localized at the smallest cross-sectional area often near the wedge grips. Figure 2.10-3 shows the failure of Specimen MAT6-TX-3-N40-FY09 indicating that failure occurs in a localized region through the specimen thickness in lieu of interlaminar failure.



Figure 2.100-3: Failure of Specimen MAT6-TX-3-N40-FY09

When the specimens were received by the research team, non-uniform dimensions were measured from one end of the specimen to the other. Therefore, failure was often just outside of the upper or lower grips where the specimen is subjected to the highest stress. To avoid localized failure near the grips and to obtain more accurate strain gauge readings, the specimen thickness was reduced using a CNC mill. The thickness was reduced from a nominal value of 0.5 in. to 0.4 in. along a 6 in. length. The specimen width was not changed. The geometry of the in-plane tension specimen was the same as the geometry used for Material 3-FY09 shown in Figure 2.10-2. All failures occurred within the 6 in. length in which the specimen thickness was reduced.

For Material 6-FY09, the elastic modulus was not always computed at a range that corresponded to 20% - 50% of the axial load capacity. Inelastic behavior was clearly observed at loads equal to 50% of the maximum axial load. Therefore, for all specimens, the elastic modulus was calculated using strains measured at 10% and 30% of the maximum axial load.

2.10.2 In-Plane Compression Test

The in-plane compression tests of Material 1-FY08, Material 2-FY08, Material 1-FY09, Material 2-FY09, Material 4-FY09, Material 5-FY09, and Material 6-FY09 were all performed as summarized in Section 2.2. No significant deviations to the testing procedure were required.

The in-plane compression tests of Material 3-FY09 were performed as summarized in Section 2.2. However, the transverse deformation behavior of this material was dissimilar to that of any other composite material part of this research. Under a uniaxial compression load, the transverse strain gauge results indicate that the thickness of the specimen initially becomes thinner upon loading and then becomes thicker. Therefore, the Poisson's ratio is initially negative and then positive under further loading. A reason for this result could not be deciphered from the experimental data or from literature. It is possible that when a compressive load is applied, the aramid fibers which are oriented across the thickness of the specimen are subjected to significant tensile stresses when the thickness tries to expand creating localized deformations in the cross-section. Poisson's ratio results are provided in Table 6.0-1 and in Appendix F for test temperatures of -40°F and 70°F. However, the results are questionable and should be used with caution. No results are given for a test temperature of 140°F.

2.10.3 In-Plane Shear Test

The in-plane shear tests of Material 1-FY08, Material 2-FY08, Material 1-FY09, Material 2-FY09, Material 4-FY09, Material 5-FY09, and Material 6-FY09 were all performed as summarized in Section 2.3. No significant deviations to the testing procedure were required.

There were no major deviations in the in-plane shear tests performed on Material 3-FY09. However, in comparison to other materials tested in this research, this material exhibits high ductility and a very small portion of the stress-strain curve exhibits elastic behavior. As shown on Pages F-37, F-43, and F-49 of Appendix F, the maximum in-plane shear stress results for all specimens are between 19,000 psi and 29,000 psi. However, the graphs presented in Appendix F only show the stress-strain curves up to a stress of approximately 9,000 psi. The strain gauges were not configured to record the high strains that the specimens were subjected to. After reviewing the data in detail and determining approximately when the stress-strain curve remains linear, the research team choose to measure elastic properties using the change in stress and strain from those recorded at 10% of the axial load capacity to those recorded at 20% of the axial load capacity (in lieu of 20% and 50%). No other significant deviations to the testing procedure were required.

2.10.4 Out-of-Plane Tension Test

The out-of-plane tension tests were performed as discussed in Section 2.4. However, the specimen geometry often changed as the project continued to progress when testing at a test temperature of 140°F. The typical specimen geometry was similar to that shown in Figure 2.8-12. For Material 2-FY08, Material 1-FY09, Material 2-FY09, Material 5-FY09, and Material 6-FY09 and at a test temperature of 140°F, the surface area at the bond line was increased as shown in Figure 2.10-4. Specimen dimensions for this configuration are shown in Figure 2.10-5. No significant deviations from the specimen geometry discussed in Section 2.4 were made for the out-of-plane tension tests of Material 1-FY08 and Material 4-FY09.

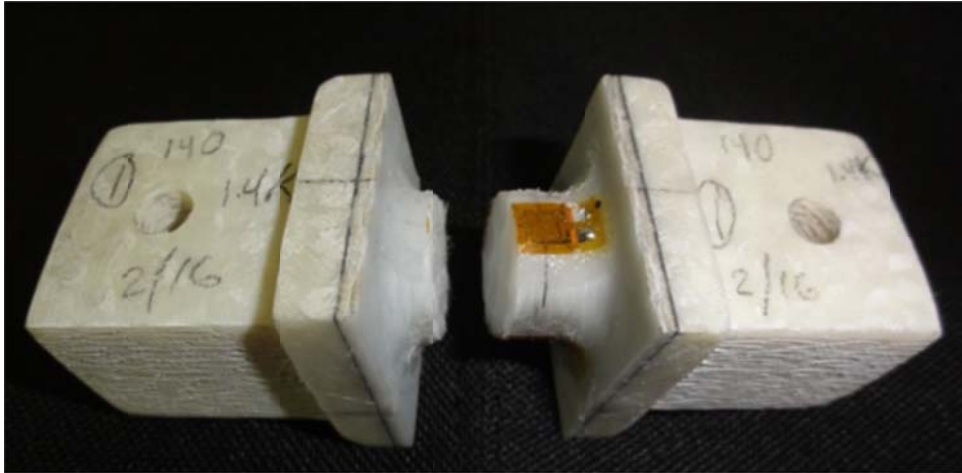


Figure 2.10-4: Out-of-Plane Tension Specimen for Material 5-FY09 at 140°F

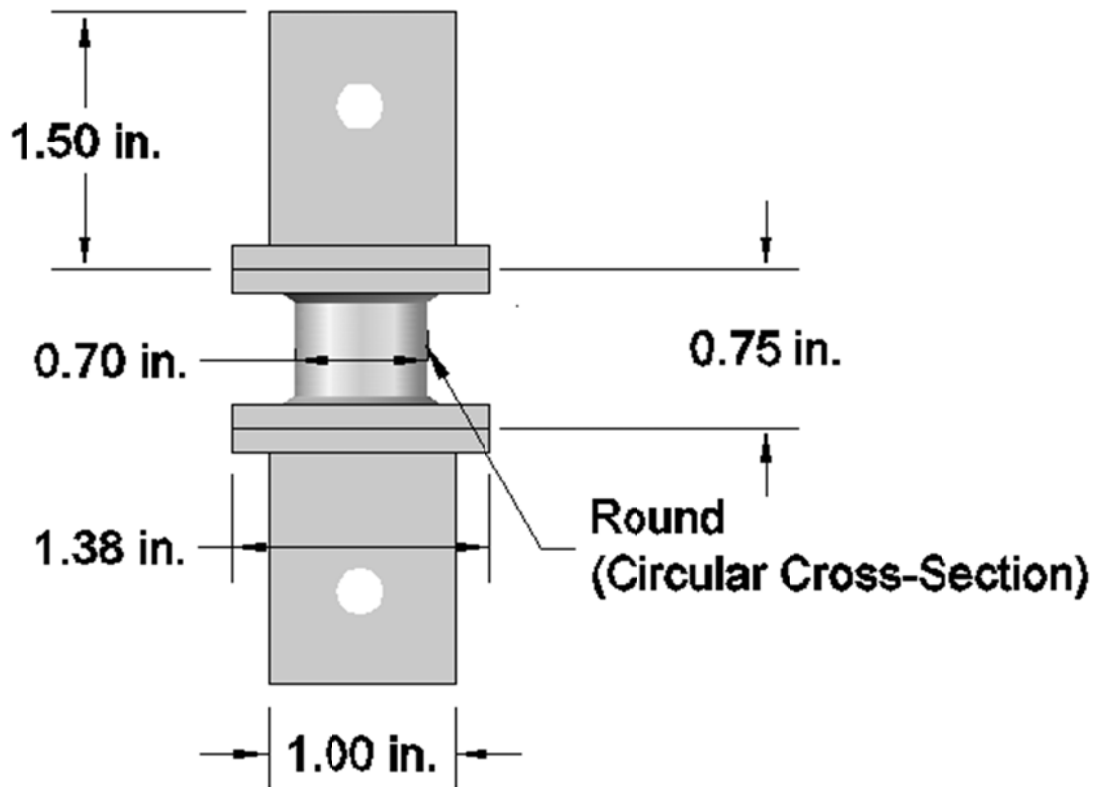


Figure 2.10-5: Out-of-Plane Tension Specimen Geometry for Select Materials at 140°F

Significant modifications to the testing procedure discussed in Section 2.4 were required to perform out-of-plane tension testing of Material 3-FY09. These modifications were due to the high

strength aramid fibers that are orientated along the 'z' axis. In summary, two different sets of tests (each set 5 specimens) were performed at each temperature. One set of tests was performed to determine the elastic modulus and one set of tests was performed to determine the tensile strength.

Initially, tests were performed as described in Section 2.4. However, the research team was unable to obtain a successful failure in the reduced section. Instead, failure repeatedly occurred at the bondline.

The first alternative method involved fabricating an additional fixture to work in conjunction with the existing fixture shown in Figure 2.4-1. This fixture adaptation was designed to change the location at which the tensile forces were introduced into the specimen. The fixture shown in Figure 2.4-1 introduces tensile forces into the specimen through pins located at the top and bottom of each specimen. The forces are distributed through the end-tab, through the bond line, and into the specimen reduced area. Hence, the entire tensile force is transferred through the bondline. No adhesives were available to withstand the tensile capacity of Material 3-FY09 even after considering multiple specimen geometries.

The new fixture was designed to attach to the fixture shown in Figure 2.4-1 and introduce load into the specimen beyond the bond line by means of bearing at the transition. Figures 2.10-6 and 2.10-7 show pictures of the original fixture both in the high load frame and with a specimen attached to half of the fixture, respectively. It should be noted that in Figure 2.10-6, a 0.25 in. gap exists between the top and bottom fixtures when loaded in the test machine. This gap allows strain gauges to attach to the test specimen.

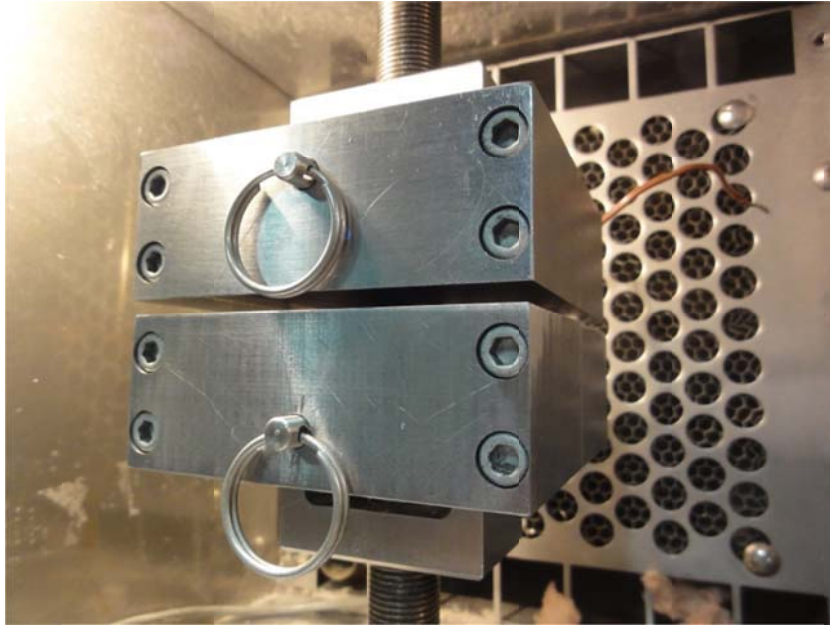


Figure 2.10-6: Fixture for Out-of-Plane Tension Testing of Material 3-FY09



Figure 2.10-7: Material 3-FY09 Specimen within Fixture for Out-of-Plane Tension Testing

For the tests conducted within the fixture shown in Figure 2.10-6, the specimen and end tab geometry shown in Figure 2.10-5 was used at ambient temperatures. This configuration had previously been used for high temperature testing only. The new fixture and testing procedure

proved to be unsuccessful. Failure did not occur due to complete debonding of the specimen to the end tab as in previous trials. Instead, the failure mode can be described by pullout of the aramid fibers from the last few layers of the glass/epoxy. Figure 2.10-8 shows a failed specimen. Black is seen at the tips of the aramid fibers indicating that they pulled away from the black epoxy used to bond the specimen to the end tab material. Therefore, failure did not occur through the thickness of the composite specimen. The approximate contact perimeter (where fixture “wraps” and contacts around the reduced section and applies initial compressive force to bondline) is shown in Figure 2.10-8. The research team concluded that the material is too thin between the edge of the transition line and the bondline. More thickness is required in order to distribute the stresses to the bondline cross-sectional area.

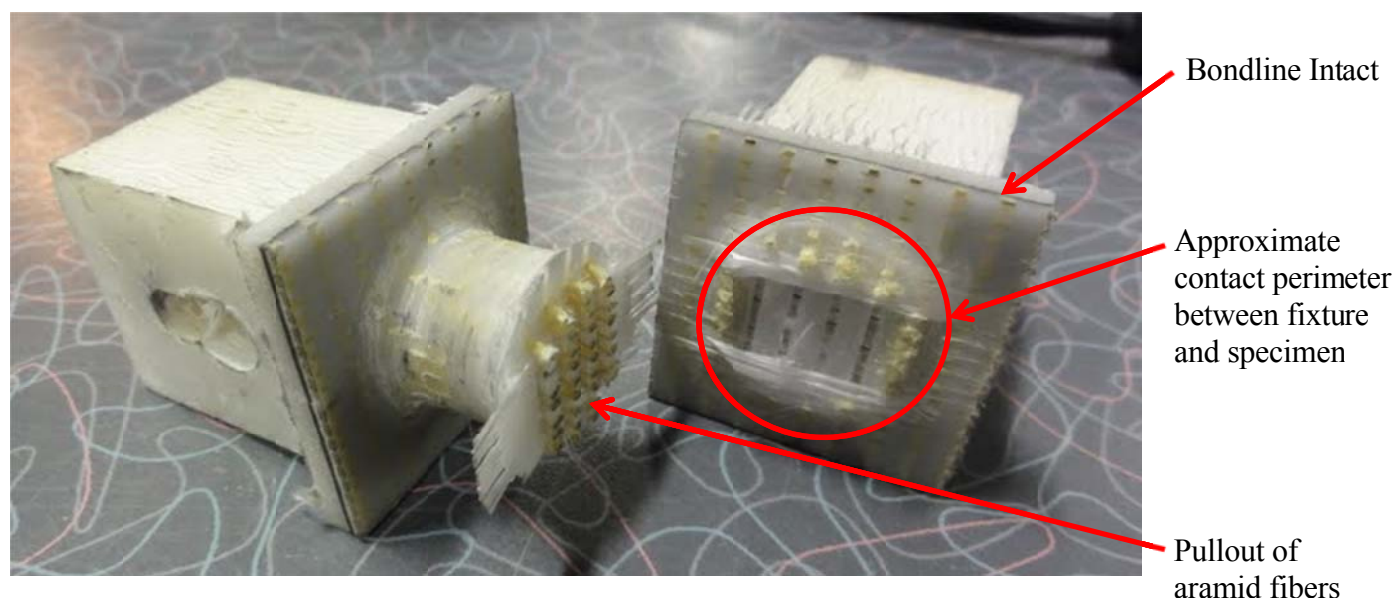


Figure 2.10-8: Failure of Material 3-FY09 Specimens due to Pullout of Aramid Fibers

The research team determined that two separate tests are required in order obtain the elastic modulus and tensile strengths individually. Specimen geometries for the two tests are shown in Figure 2.10-9. The individual tests have been identified as “Elastic Tests” which were used to determine the elastic modulus and “Fracture Tests” which were used to determine the ultimate stress.

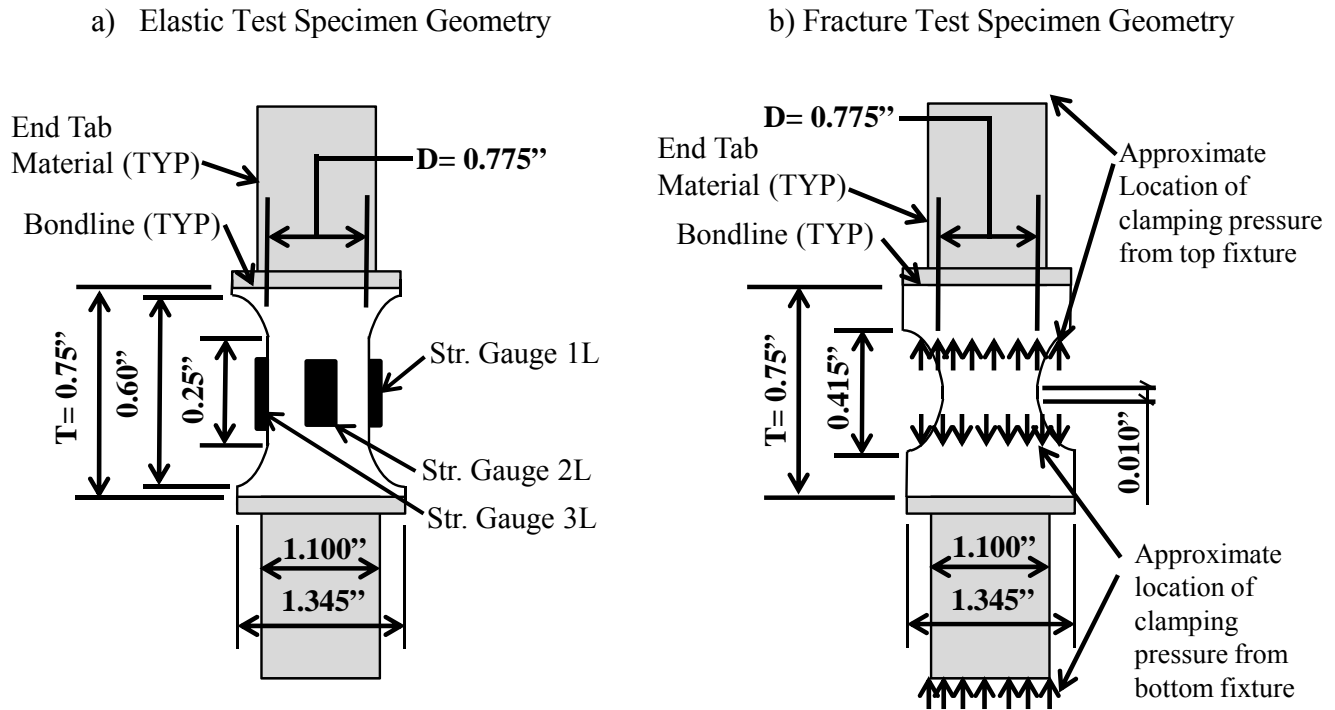
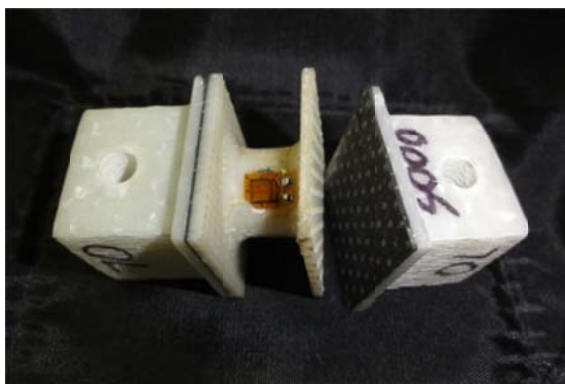


Figure 2.10-9: Specimen Geometry for (a) Elastic Tests and (b) Fracture Tests (NTS)

As shown in Figure 2.10-9(b), the depth of the reduced section (depth of constant cross-sectional area) is decreased for the Fracture Tests from 0.25 in. to 0.01 in. which is null. This increases the thickness of the material adjacent to the bondline, thus distributing the stresses more efficiently when subjected to the compressive force from clamping (discussed later). However, a strain gauge cannot be attached to the reduced section of the Fracture Test specimen. Therefore, as shown in Figure 2.10-9(a), a specimen geometry similar to that discussed in Section 2.4.1 was used to measure the elastic properties. Figure 2.10-10(a) and 2.10-10 (b) show pictures of failed Elastic and Fracture specimens, respectively.

a) Material 3-FY09, Elastic Specimen



b) Material 3-FY09, Fracture Specimen

**Figure 2.10-10: Material 3-FY09 Out-of-Plane Tension Spec., (a) Elastic and (b) Fracture**

For the Elastic Test, three longitudinal strain gauges were adhered to the specimen 120° apart. The average elastic modulus as interpreted from the three strain gauges is reported for the elastic modulus of each specimen. The nomenclature used to identify the specimens for the Elastic Test consists of “TZE” to differentiate from the specimens used for the Fracture Test. At 70°F, the elastic modulus was computed using changes in stresses and strains recorded when the load corresponded to 10% of the maximum load to when the load corresponded to 40% of the maximum load. The maximum load was determined using the average ultimate strength measured during the Fracture tests. For the testing conducted at 140°F and -40°F, the elastic modulus was computed using changes in stresses and strains recorded when the load corresponded to 10% of the maximum load to when the load corresponded to 35% of the maximum load.

As previously mentioned, the Fracture Test is used to determine the ultimate strength. In order to further ensure that failure does not occur due to high tensile stresses at the bondline, each bondline is clamped using fixtures (top and bottom) similar to that shown in Figures 2.10-6 and 2.10-7. More discussion on why an initial clamping force was applied is discussed later. Figure 2.10-11 shows a plan view of the fixtures and Figure 2.10-12 shows an elevation view. Figure 2.10-13 shows the fixture dimensions and Figure 2.10-14 shows an illustration of how the fixture attaches to the specimen and to the fixture shown in Figure 2.4-1.



Figure 2.10-11: Plan View of $\frac{1}{2}$ of Fixture (Bottom) (a) With and (b) Without Specimen

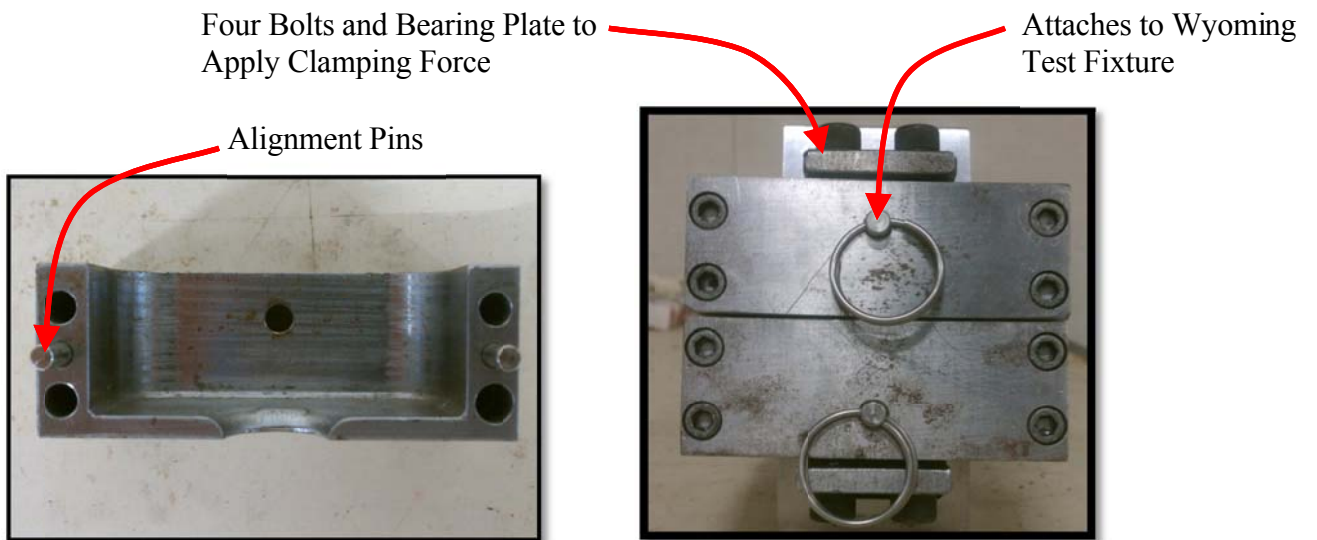
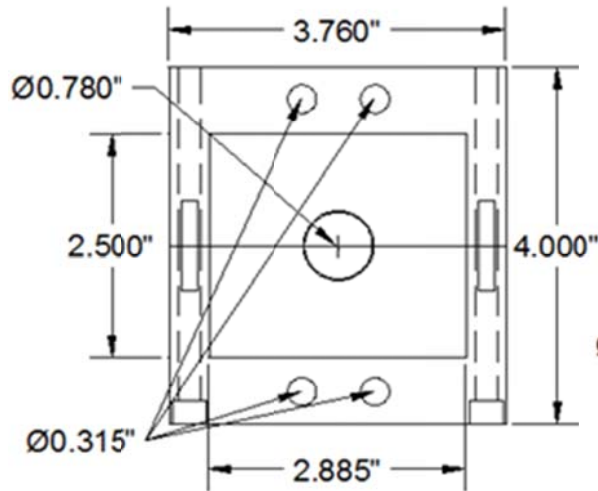
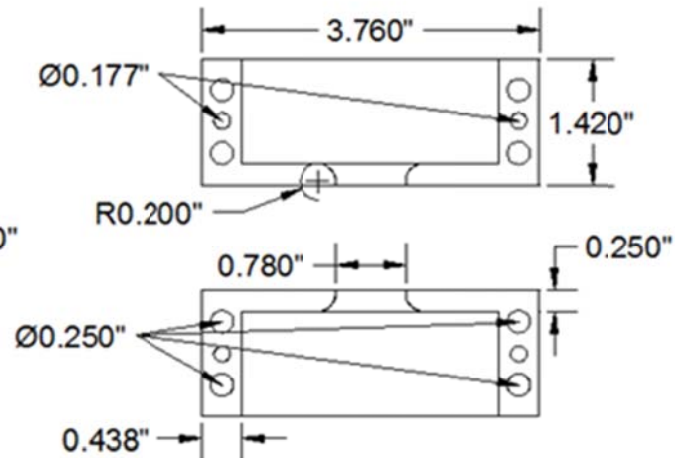
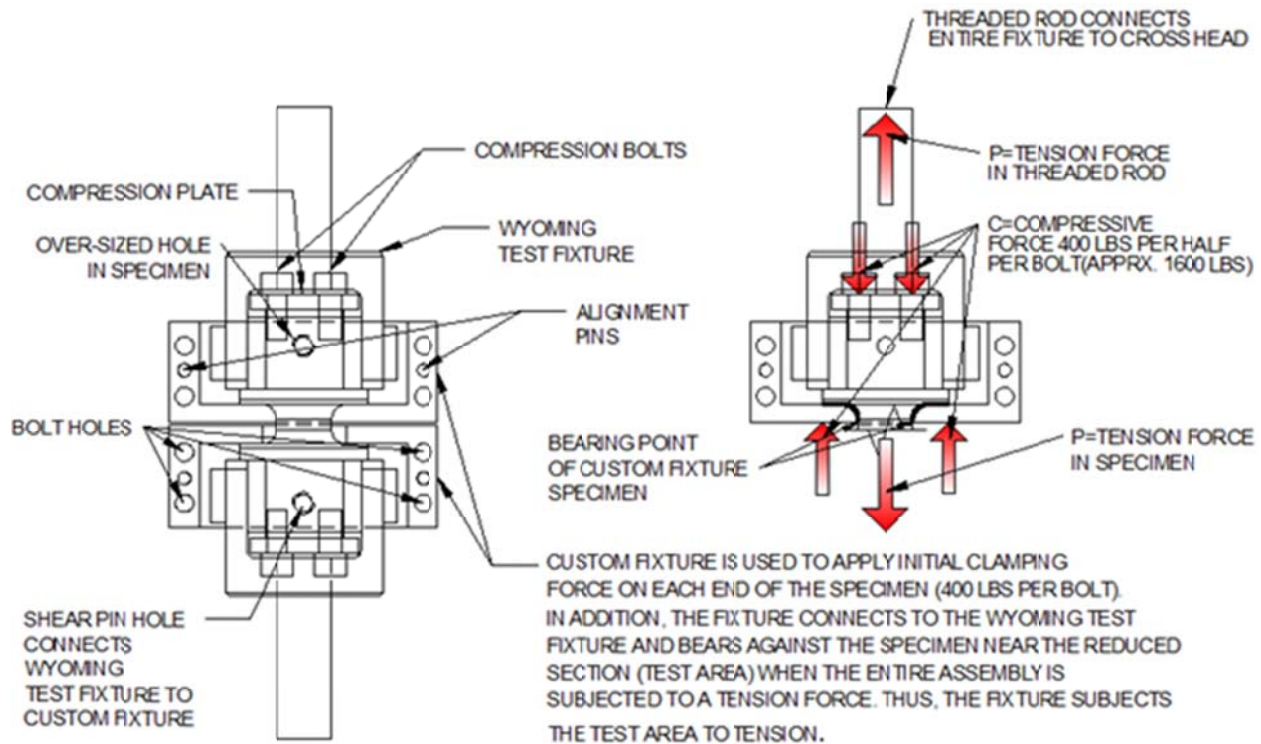


Figure 2.10-12: Elevation of (a) Section of Bottom Half of Fixture and (b) Halves Connected

a) Plan View



b) Elevation View

**Figure 2.10-13: Fixture Dimensions (a) Plan View and (b) Elevation View**

NOTE:
FORCES ARE APPLIED TO BOTH THE UPPER AND LOWER HALF. THE DIAGRAM ONLY DISPLAY FORCES APPLIED TO THE UPPER HALF FOR CLARITY.

Figure 2.10-14: Illustration of Fixture Elevation and Connection to Specimen

The fixture attachment applies the tensile force to the specimen by contact at the transition area which is beyond the bondline (i.e. closer to reduced section). Still, due to deformations that develop in the test setup, an initial clamping force is required to ensure the bondline doesn't fail. Figure 2.10-14 illustrates that the fixture applies an initial compressive force in the bondline prior to the application of tensile force in the specimen. This is further illustrated using Figure 2.10-15 with a free body diagram that identifies the internal forces at the bondline and the internal forces in the reduced section. The clamping force is applied by tightening the bolts that are part of the fixture. The approximate magnitude is 1600 lbs. To apply the clamping force, one side of the fixture attaches to the end of the specimen and the other flares around the transition area. The nomenclature used to identify the specimens for the Elastic Test consists of "TZE" to differentiate from the specimens used for the Fracture Test.

a) Force in Test Section

b) Force on Bondline

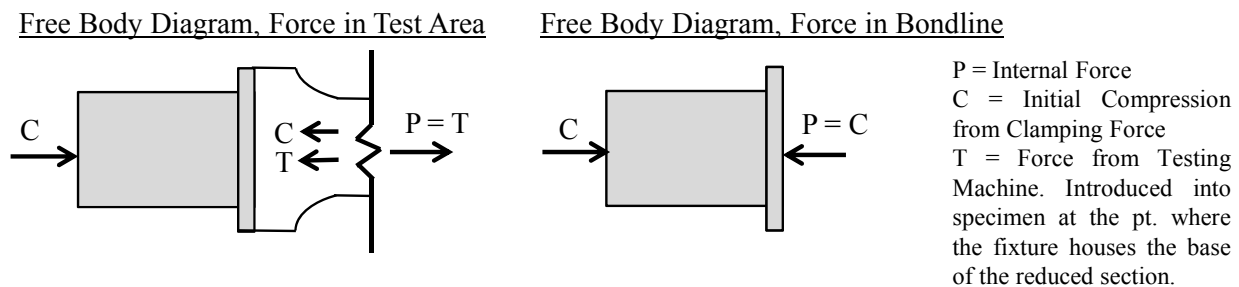


Figure 2.10-15: Free Body Diagram Showing Forces at Bondline and on Reduced Section

2.10.5 Out-of-Plane Compression Test

The out-of-plane compression tests for all materials were all performed as summarized in Section 2.5. No significant deviations to the testing procedure were required. However, for Material 2-FY09 and Material 1-FY09 and at a temperature of 140°F, the elastic modulus was calculated using the stresses and strains measured at loads corresponding to 10% and 40% of the axial load capacity in lieu of 20% and 50% of the axial load capacity.

2.10.6 Out-of-Plane Shear Test

The out-of-plane shear tests of Material 1-FY08, Material 2-FY08, Material 1-FY09, Materials 2-FY09, Material 4-FY09, and Material 5-FY09 were all performed as summarized in Section 2.6. The nominal notch length from Figure 2.6-2 is 0.30 in. However, for Material 1-FY08, the nominal notch length was 0.24 in. and for Material 4-FY09, the nominal notch length was 0.25 in. No other significant deviations were required for the out-of-plane shear testing of these materials.

Significant variations to the test specimen geometry were required to complete the out-of-plane shear testing of Material 3-FY09. Initially, the specimen geometry shown in Figure 2.6-2 was used and two specimens were tested successfully at a test temperature of 70°F. However, other specimens tested with the geometry shown in Figure 2.6-2 were unsuccessful with failure occurring repeatedly at the bondline. The research team was unable to reduce the notch length (NL) since it would disallow the attachment of strain gauges. Therefore, the research team reduced the depth (D) from a nominal value of 0.50 in. to a nominal value of 0.30 in. by transitioning as shown in Figure 2.10-16 (actual D approximately 0.277" as shown in Figure 2.10-16).

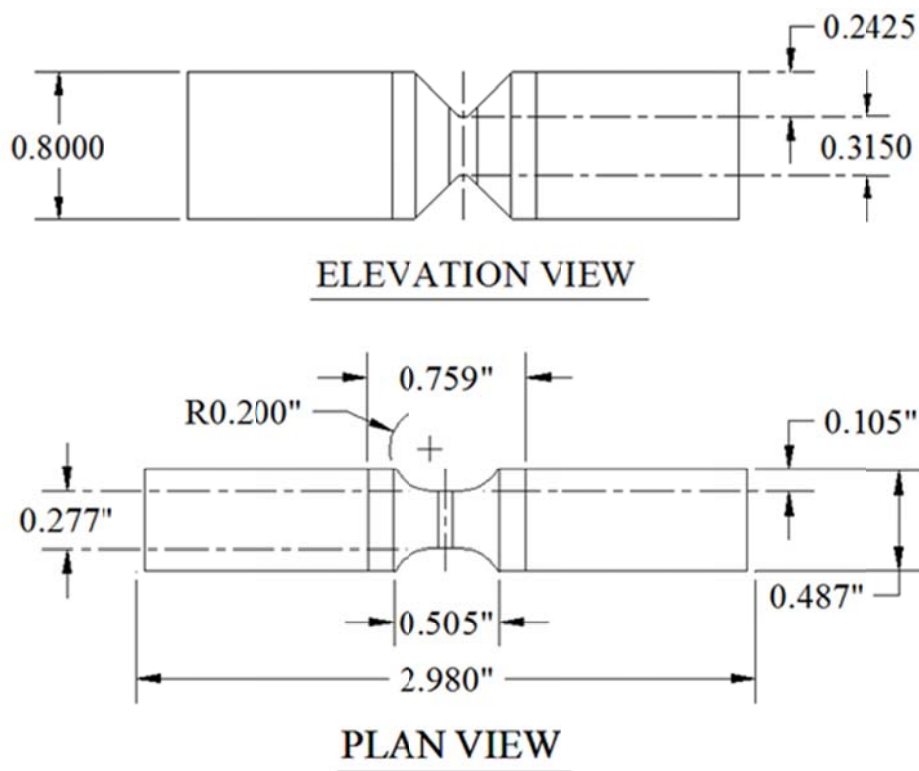


Figure 2.10-16: Out-of-Plane Shear Specimen Geometry for Material 3-FY09

The out-of-plane shear tests of Material 6-FY09 were performed as summarized in Section 2.6 without significant deviations. Several tests were performed at each test temperature with five reasonably consistent results shown for each test temperature in Appendix I. However, the ultimate shear strength results were scattered. In addition, the specimens often did not fail at the minimum cross-section. This can be identified in the post-test pictures part of Appendix I. None of the failures occurred outside of the material tested or at the bondline and all failures are within the acceptable limits of ASTM D 5379. Therefore, the research team is comfortable with presenting the results of the specimens tested knowing that the material is capable of resisting the maximum stress at the notch location.

2.10.7 Out-of-Plane Poisson's Ratio Test

The Poisson's ratio tests were performed as discussed in Section 2.7. For Material 1-FY08, the tests conducted at 70°F and -40°F were performed using metal end tabs and the tests conducted at 140°F were performed using end tabs made from composite materials. For Material 4-FY09, the tests conducted at -40°F were performed using metal end tabs and the tests conducted at 70°F and 140°F were performed using end tabs made from composite materials. All other materials were tested using end tabs made from composite materials.

In Section 2.7, it is noted that the Poisson's ratio is usually calculated using strains measured when the axial load is equal to 20% of the maximum axial load and 50% of the maximum axial load. The maximum axial load is calculated using the results of the out-of-plane tension tests. However, for Material 1-FY08 and at a temperature of 140°F, strains at 10% and 35% of the maximum axial load were used.

For Material 2-FY08, Material 1-FY09, Material 2-FY09, Material 5-FY09, and Material 6-FY09 and at a maximum temperature of 140°F, the surface area at the bond line was increased as shown in Figure 2.10-17. Specimen dimensions for this configuration are shown in Figure 2.10-18.



Figure 2.10-37: Poisson's Specimen for Material 5-FY09 at 140°F

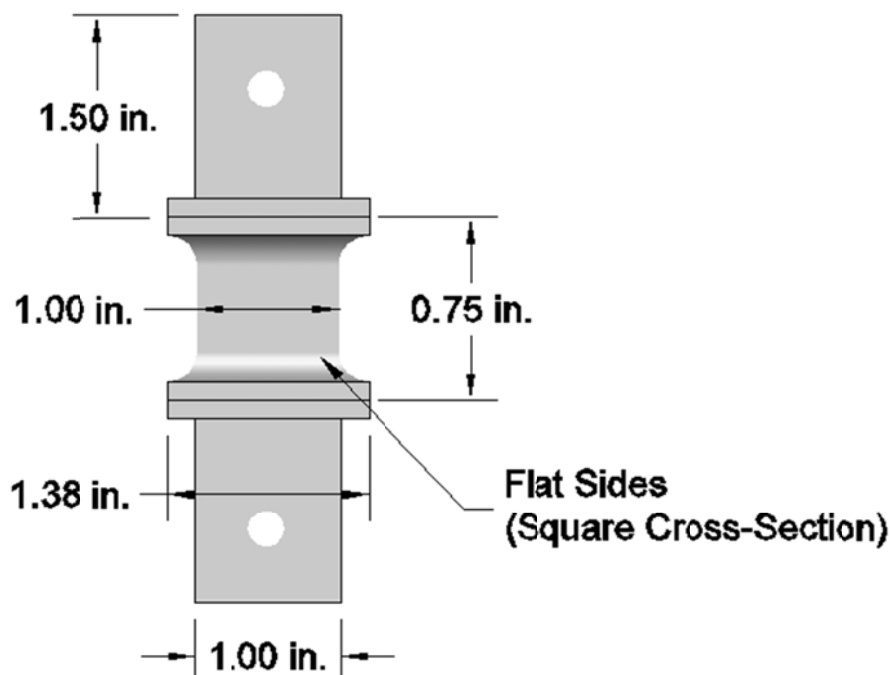


Figure 2.10-18: Dimensions for Out-of-Plane Poisson's Select Specimens at 140°F

At 140°F, the results for materials with Huntsman Rencast 6405 and S2-glass were unfavorable which is dissimilar from the results obtained for materials with API SC-15 epoxy. At this temperature, six (6) specimens were tested for Material 1-FY09, six (6) specimens were tested for Material 2-FY09, and fourteen (14) specimens were tested for Material 2-FY08. The five specimens with the most representative data of the material behavior of the composite specimens are presented for each material in the appendices. More problematic results occurred for Material 2-FY08 as discussed in this section.

For most materials tested in this research, the transverse strain readings recorded during the out-of-plane Poisson's test are negative indicating that the cross-sectional area of the specimen is decreasing in size under tensile loading. However, for materials with Huntsman Rencast 6405 and S2-glass and at the temperature of 140°F, several of the transverse strain readings were positive indicating that the cross-sectional area is increasing under tensile loading. Therefore, several of the results are unexpected. For Material 1-FY09 and Material 2-FY09, the research team decided that several of the transverse strain gauge results are invalid. Therefore, several transverse strain gauge results were not considered in the reported Poisson's ratios of the materials. Overall, at this temperature, the results are sporadic and the out-of-plane Poisson's ratio for all materials with Huntsman Rencast 6405 and S2-glass at this temperature should be used with caution.

For Material 2-FY08 and at a test temperature of 140°F, almost all transverse strain gauge readings were positive for the five specimens reported in Appendix C. Therefore, the final Poisson's ratio is shown as negative in Table 5.0-1. This result is improbable but the results were fairly consistent for the five specimens and the other nine specimens that were not considered in the average result. Since a total of fourteen specimens were tested, the research team performed no further studies to validate the results.

For Material 2-FY09 and at a test temperature of 140°F, only four of the six tests were found to have reasonable results. In addition, for three of the four tests, at least one strain gauge was discarded. The research team did not have any additional material available to fabricate more specimens but did not feel that more specimens would assist in eliminating the sporadic results.

For Material 3-FY09, strain gauges were attached on all four sides of the first specimen tested at 70°F and the first two specimens tested at 140°F. This strain gauge configuration was used to ensure that similar results were obtained on adjacent sides of the specimen and the v_{xz} and the v_{yz} results are similar. The results were found to be similar and gauges were only attached to two adjacent sides for further testing as described in Section 2.7.

For Material 3-FY09 and at -40°F, tests were performed as described in Section 2.7 without any major deviations. For the testing performed at test temperatures of 70°F and 140°F, several of the strain gauges malfunctioned and accurate readings were not obtained during the test.

Therefore, the gauge readings were not considered for measuring the Poisson's ratio. At a test temperature of 140°F, strains at 5% and 20% of the maximum axial load were used since failures occurred prematurely at the bondline. At a test temperature of 70°F, a range of 10%-40% was used.

Dissimilar from other materials part of this research, the v_{xz} and v_{yz} Poisson's ratio results varied significantly for Material 6-FY09. Therefore, strain gauges were used to measure longitudinal and transverse strain on all four sides of the specimen. Two are used to measure v_{xz} and two are used to measure v_{yz} . Figure 2.10-19 shows an illustration of the specimen dimensions and picture of a specimen in which the top end tab has been removed. Figure 2.10-19 also shows the assumed material axes. Measurements for v_{xz} are taken on Sides 1 and 3 and measurements for v_{yz} are taken on Sides 2 and 4. of a specimen which also indicates which property is measured on each of the four sides. As shown in the picture, horizontal black lines which are carbon fibers are more evident on Sides 1 and 3.

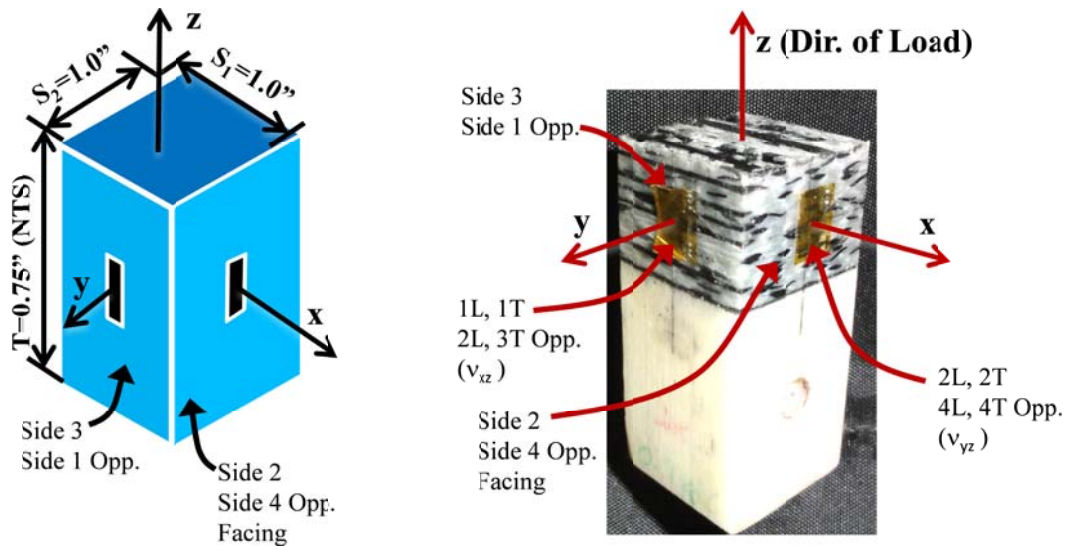


Figure 2.10-4: Specimen Geometry and Poisson's Ratio Measurements for Material 6-FY09

CHAPTER 3: ACCEPTANCE TESTING

This chapter summarizes the results of all the acceptance testing. Deviations from the testing procedures described in Chapter 2 for the final results are discussed in this chapter. All results are summarized in Appendix A. There was no predefined number of specimens required to validate the procedure for each test. After several iterations, the research team considered the acceptance testing complete when comfortable with the procedures, strain gauge configuration, and when a minimum of five sequential tests were considered acceptable. This was required at each temperature of each test type. Only the results of the five sequential tests that were considered acceptable are included in Appendix A.

Table 3.0-1 lists the results of the material properties given in Table 1.3-2 for the acceptance tests. These results represent the average results of the 5 specimens tested. More results and other information from the test such as graphs of the stress-strain data, ultimate strains, and other relevant test information are found in Appendix A. The results and exceptions to the testing procedures discussed in Chapter 2 will be discussed in the following subsections.

Table 3.0-1: Acceptance Test Material Testing Results

| Test | Property | Acceptance, Temperature | | |
|--------------------------|--|-------------------------|---------|---------|
| | | -40°F | 70°F | 140°F |
| In-Plane Tension | Tensile Strength, ST_x or ST_y (psi) | 41419 | 42732 | 38160 |
| | Tensile Modulus, E_x or E_y (psi) | 2114380 | 2461795 | 2363494 |
| | Poisson Ratio, ν_{xy} | 0.2235 | 0.213 | 0.2358 |
| In-Plane Compression | Compressive Strength, SC_x or SC_y (psi) | 37155 | 39480 | 31378 |
| | Compressive Modulus, EC_x or EC_y (psi) | 2953429 | 3000782 | 2942843 |
| | Poisson Ratio, ν_{xy} | 0.283 | 0.280 | 0.367 |
| In-Plane Shear | Shear Strength, S_{xy} (psi) | 32255 | 25929 | 24338 |
| | Shear Modulus, G_{xy} (psi) | 1751870 | 1375199 | 1351465 |
| Out-of-Plane Tension | Tensile Strength, ST_z (psi) | 2494 | 2318 | 1256 |
| | Tensile Modulus, E_z (psi) | 1675613 | 1400195 | 1282549 |
| Out-of-Plane Compression | Compressive Strength, SC_z (psi) | 110720 | 88327 | 79397 |
| | Compressive Modulus, EC_z (psi) | 1395380 | 1181799 | 1162693 |
| Out-of-Plane Shear | Shear Strength, S_{xz} or S_{yz} (psi) | 4877 | 4137 | 2853 |
| | Shear Modulus, G_{xz} or G_{yz} (psi) | 948947 | 820919 | 530676 |
| OP Poisson | Poisson Ratio, ν_{xz} or ν_{yz} | 0.174 | 0.177 | 0.179 |

3.1 Acceptance Testing: In-Plane Tension

Sheet A-1 (of Appendix A, typical) summarizes the results for the in-plane tension tests (Test 1) conducted at a temperature of -40°F. In lieu of the procedures discussed in Section 2.1.2, the specimens were fitted with two Vishay 125-UW strain gauges and two Vishay 125-LT strain gauges. The Vishay 125-LT gauges were used to measure the longitudinal and transverse strain on two sides. Individual specimen results are summarized on A-2 to A-6. The best 5 sequential specimen results are reported and have been designated as MATA-TX-1-N40 to MATA-TX-5-N40. As shown on Sheet A-7, the tensile strength (ST_x or ST_y) is averaged as 41,419 psi, the elastic modulus (E_x or E_y) is averaged as 2,114,380 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as

0.223. The data is fairly consistent for the tensile strength and the elastic modulus. However, significant deviation is found in the Poisson's ratio results.

Sheet A-7 summarizes the results for the in-plane tension tests conducted at a temperature of 70°F. Individual specimen results are summarized on A-8 to A-12. The specimens were fitted with three Vishay 125-UW strain gauges and one Vishay 125-LT strain gauge. The Vishay 125-LT was used to measure the longitudinal and transverse strain. Two Vishay 125-LT gauges were fitted on MATA-TX-5-70 to measure the Poisson's ratio on two sides. The in-plane tension tests conducted at a temperature of 70°F were the first tests conducted by the research team. Therefore, the research team was becoming familiar with specimen behavior and discarded the results of the original first 5 specimens tested. After all tests were complete, the research team was comfortable with the testing procedure, strain gauge readings, and data processing. The best 5 sequential specimen results are reported and have been designated as MATA-TX-1-70 to MATA-TX-5-70.

As shown on Sheet A-7, the tensile strength (ST_x or ST_y) is averaged as 42,732 psi, the elastic modulus (E_x or E_y) is averaged as 2,461,795 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as 0.213. The Poisson's ratio data is somewhat scattered but this scatter is consistent in this research. There is a slight increase in both the tensile strength and the elastic modulus as compared to the tests conducted at -40°F. However, the material tested during the acceptance testing was fabricated at different times. Therefore, direct comparisons are questionable.

Sheet A-13 summarizes all of the results for the in-plane tension tests (Test 1) conducted at a temperature of 140°F. Individual test results are summarized on A-14 to A-18. As shown on Sheet A-13, the tensile strength (ST_x or ST_y) is averaged as 38,160 psi, the elastic modulus (E_x or E_y) is averaged as 2,363,494 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as 0.236. The specimens were fitted with three Vishay 125-UW strain gauges and one Vishay 125-LT strain gauge. There is a significant decrease in the tensile strength as opposed to that measured at ambient temperatures. There is no significant change in the elastic modulus.

3.2 Acceptance Testing: In-Plane Compression

The in-plane compression testing procedures discussed in Section 2.2 were followed directly for the acceptance testing. There were no major deviations.

Sheet A-19 summarizes all of the results for the in-plane compression tests (Test 2) conducted at a temperature of -40°F. Individual test results are shown on A-20 to A-24. As shown on Sheet A-19, the compressive strength (SC_x or SC_y) is averaged as 37,155 psi, the elastic modulus (EC_x or EC_y) is averaged as 2,953,429 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as 0.283. Note that both the elastic modulus and the Poisson's ratio were noticeably higher than the values measured for in-plane tension at a temperature of -40°F.

Sheet A-25 summarizes all of the results for the in-plane compression tests (Test 2) conducted at ambient temperatures. Individual test results are shown on A-26 to A-30. As shown on Sheet A-25, the compressive strength (SC_x or SC_y) is averaged as 39,480 psi, the elastic modulus (EC_x or EC_y) is averaged as 3,000,782 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as 0.28. Consistent results are found for all three measurements. Note that both the elastic modulus and the Poisson's ratio were noticeably higher than the values measured for in-plane tension at ambient temperatures.

Sheet A-31 summarizes all of the results for the in-plane compression tests (Test 2) conducted at a temperature of 140°F. Individual test results are shown on A-32 to A-36. As shown on Sheet A-31, the compressive strength (SC_x or SC_y) is averaged as 31,378 psi, the elastic modulus (EC_x or EC_y) is averaged as 2,942,843 psi, and the in-plane Poisson ratio (ν_{xy}) is averaged as 0.367. The results are somewhat scattered. The compressive strength decreases significantly in comparison to the in-plane compressive strength at ambient temperatures. There is not a significant difference in the elastic modulus but there is a significant increase in the Poisson ratio.

Overall, at all three temperatures, the acceptance test results indicate that the elastic modulus and Poisson's ratio vary depending on whether or not the specimen is in tension or compression.

3.3 Acceptance Testing: In-Plane Shear

Several iterations were conducted during the acceptance testing to verify the testing procedure, strain gauges, and other equipment used to perform the in-plane shear tests per ASTM D 7078/D 7078M. Initially, a fixture was purchased by LTU that was designed by MTT per ASTM D 7078/D 7078M. However, this fixture failed and a new fixture had to be purchased and designed

with a much higher shear load capacity. This section will only discuss the acceptance test results using the new shear fixture.

Sheet A-37 summarizes all of the results for the in-plane shear tests (Test 3) conducted at a temperature of -40°F. Individual test results are shown on A-38 to A-42. As shown on Sheet A-37, the in-plane shear strength (S_{xy}) is averaged as 32,255 psi and the in-plane shear modulus (G_{xy}) is averaged as 1,751,870 psi. The results of four of the five specimens are consistent. The results of Specimen MATA-SXY-N40-01 are significantly different than the other four specimens. However, this was the first specimen tested at this temperature and the research team was comfortable after performing the remaining four tests.

Sheet A-43 summarizes all of the results for the in-plane shear tests (Test 3) conducted at ambient temperatures. Individual test results are shown on A-44 to A-48. As shown on Sheet A-43, the in-plane shear strength (S_{xy}) is averaged as 25,929 psi and the in-plane shear modulus (G_{xy}) is averaged as 1,375,199 psi. The results of the five specimens tested are fairly consistent. Both the in-plane shear strength and the in-plane shear modulus decreased in comparison to the tests performed at cold temperatures.

Sheet A-49 summarizes all of the results for the in-plane shear tests (Test 3) conducted at a temperature of 140°F. Individual test results are shown on A-50 to A-54. As shown on Sheet A-49, the in-plane shear strength (S_{xy}) is averaged as 24,338 psi and the in-plane shear modulus (G_{xy}) is averaged as 1,351,465 psi. The results of all five specimens are consistent. Both the in-plane shear strength and the in-plane shear modulus decreased slightly in comparison to the tests performed at ambient temperatures.

3.4 Acceptance Testing: Out-of-Plane Tension

Significant variations in the testing procedure discussed in Section 2.4 were performed during the out-of-plane tension acceptance testing. Several specimens were tested under ambient conditions. Initially, the specimens were cylindrical without spooling and bonded to metal test adapters. The results indicated insufficient bond strength between the material and the adapters. It was originally assumed that the debonding was due to eccentricities in the test setup. The specimens were then bonded to metal end tabs which were pinned to the test fixture shown in Figure 2.4-1. However,

the failure always occurred at the bond between the end tabs and the specimen tested. Therefore, the specimens were spooled as shown in Appendix A.

For the results presented in this section, the ambient and cold temperature specimens were still bonded to metal end tabs which proved to be insufficient for hot testing due to debonding at the specimen/end tab interface. In addition, the nominal reduced diameter of the ambient and cold temperature specimens was equal to 0.9 in. in lieu of 0.75 in. (See Figure 2.4-3). All specimens were fitted with Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

Sheet A-55 summarizes all of the results for the out-of-plane tension tests (Test 4) conducted at a temperature of -40°F. Individual test results are summarized on A-56 to A-60. As shown on Sheet A-55, the tensile strength (ST_z) is averaged as 2,494 psi and the elastic modulus (E_z) is averaged as 1,675,613 psi. The values are relatively consistent among the specimens tested for both properties.

Sheet A-61 summarizes all of the results for the out-of-plane tension tests (Test 4) conducted at ambient temperatures. Individual specimen results are summarized on A-62 to A-66. Refer to these sheets for modified specimen dimensions. As shown on Sheet A-61, the tensile strength (ST_z) is averaged as 2,318 psi and the elastic modulus (E_z) is averaged as 1,400,195 psi. Consistent results are found for the tensile strength but some scatter is found for the elastic modulus. There is a decrease in both the tensile strength and the elastic modulus as compared to the tests conducted at cold temperatures.

Due to material availability, the out-of-plane tension acceptance tests performed at 140°F were not conducted with the same material as that for -40°F and 70°F. Instead, Material 4-FY09 was used to fabricate additional specimens for the acceptance testing at 140°F. Therefore, the effects of temperature will not be discussed. In addition, specimens at 140°F were tested using end tabs made from the same material as the specimen. The completed test specimens were fabricated using the procedures discussed in Section 2.8.

Sheet A-67 summarizes all of the results for the out-of-plane tension tests (Test 4) conducted at a temperature of 140°F. Individual test results are summarized on A-68 to A-72. As shown on Sheet A-67, the tensile strength (ST_z) is averaged as 1,256 psi and the elastic modulus (E_z) is averaged as 1,282,549 psi. The tensile strength results of specimen MATA-TZ-1-140 was

significantly lower than that of the other four. However, since the results of the last four specimens tested were somewhat consistent, the research team felt comfortable with the testing procedure.

3.5 Acceptance Testing: Out-of-Plane Compression

Out-of-plane compression testing was performed using the procedure outlined in Section 2.5. Initially, the research team used 1.125" diameter cylinders. However, the failure loads were in excess of 100 kips and the platens of the MTS machine attachments were not able to support the load. Therefore, for the acceptance testing, the nominal diameter was reduced to 0.75". This nominal diameter was determined adequate for performing the test and did not cause damage to the equipment. However, it was cumbersome to apply strain gages to the face of the specimens. Therefore, a 0.85" nominal diameter was chosen for further testing which did not cause damage to the equipment.

Sheet A-73 summarizes all of the results for the out-of-plane compression tests (Test 5) conducted at a temperature of -40°F. Individual test results are shown on A-74 to A-78. As shown on Sheet A-73, the compressive strength (SC_z) is averaged as 110,720 psi and the elastic modulus (EC_z) is averaged as 1,395,380 psi. The out-of-plane compressive strength is much higher than the in-plane compressive strength and the elastic modulus is much lower. The out-of-plane compressive strength is significantly higher than the out-of-plane tensile strength. The compressive elastic modulus is slightly lower than the tensile elastic modulus.

Sheet A-79 summarizes all of the results for the out-of-plane compression tests (Test 5) conducted at ambient temperatures. Individual test results are shown on A-80 to A-84. As shown on Sheet A-79, the compressive strength (SC_z) is averaged as 88,327 psi and the elastic modulus (EC_z) is averaged as 1,181,799 psi. The compressive strength is much higher than the in-plane compressive strength and the elastic modulus is much lower. The out-of-plane compressive strength is significantly higher than the out-of-plane tensile strength. The elastic modulus is slightly lower. Both the elastic modulus and the compressive strength decrease in comparison to out-of-plane compression tests at cold temperatures.

Sheet A-85 summarizes all of the results for the out-of-plane compression tests (Test 5) conducted at a temperature of 140°F. Individual test results are shown on A-86 to A-90. As

shown on Sheet D-13, the compressive strength (SC_z) is averaged as 79,397 psi and the elastic modulus (EC_z) is averaged as 1,162,693 psi. Similar to the ambient and cold comparisons, the out-of-plane compressive strength is much higher than the in-plane compressive strength and the elastic modulus is much lower. The out-of-plane compressive strength is significantly higher than the out-of-plane tensile strength. Both the elastic modulus and the compressive strength decrease in comparison to out-of-plane compression tests at ambient temperatures.

3.6 Acceptance Testing: Out-of-Plane Shear

The out-of-plane shear acceptance tests were not performed using the same material as the other acceptance tests. Instead, additional Material 1-FY09 specimens were fabricated and used to perform the tests. Several iterations were performed to determine specimen fabrication methods and resolve bonding issues at the 'end tabs'. The results presented in this section were based on results obtained using testing and fabrication methods discussed in Sections 2.6 and 2.8 only.

Sheet A-91 summarizes all of the results for the out-of-plane shear tests (Test 6) conducted at a temperature of -40°F. Individual test results are shown on A-92 to A-96. As shown on Sheet A-91, the out-of-plane shear strength (S_{xz} or S_{yz}) is averaged as 4,877 psi and the out-of-plane shear modulus (G_{xz} or G_{yz}) is averaged as 948,947 psi. The results show discrepancies in the five specimens tested for both the out-of-plane shear strength and the out-of-plane shear modulus. However, the resulting stress-strain curves are linear and consistent readings are found for each gauge on one specimen.

Sheet A-97 summarizes all of the results for the out-of-plane shear tests (Test 6) conducted at ambient temperatures. Individual test results are shown on A-98 to A-102. As shown on Sheet A-97, the out-of-plane shear strength (S_{xz} or S_{yz}) is averaged as 4,137 psi and the out-of-plane shear modulus (G_{xz} or G_{yz}) is averaged as 820,919 psi. The results of the five specimens tested indicate scatter in both the out-of-plane shear strength and the out-of-plane shear modulus. The results also indicate that both properties decrease when compared to the results obtained at -40°F.

Sheet A-103 summarizes all of the results for the out-of-plane shear tests (Test 6) conducted at a temperature of 140°F. Note that the individual specimens are numbered in the order that they were tested and some tests were omitted from the results. Individual test results are shown on A-

104 to A-108. As shown on Sheet A-103, the out-of-plane shear strength (S_{xz} or S_{yz}) is averaged as 2,853 psi and the out-of-plane shear modulus (G_{xz} or G_{yz}) is averaged as 530,676 psi. The results of all five specimens are consistent. The results also indicate that the out-of-plane shear strength and the out-of-plane shear modulus decrease significantly at 140°F in comparison to ambient temperatures.

3.7 Acceptance Testing: Out-of-Plane Poisson

LTU performed several iterations to develop the procedure used for the out-of-plane Poisson's ratio tests. The primary issue was the bond between the material tested and the end tabs. As discussed in Section 2.8, the final Poisson's ratio tests were performed with specimens bonded to end tabs made from other composite materials. However, the acceptance testing was performed using various procedures depending on the test temperature:

- Ambient: Specimen set into a pool of epoxy attaching directly to metal test fixtures.
- -40°F: Specimen bonded to metal end tabs which were attached to the test fixture shown in Figure 2.4-1.
- 140°F: Specimen bonded to end tabs made of the same composite material which were attached to the test fixture shown in Figure 2.4-1.

As mentioned in Section 2.7, the test was considered successful if the axial load at failure was greater than 50% of the axial load capacity which was determined using the out-of-plane tension test results. Some of the specimens tested had nominal dimensions of 0.7 in. x 0.7 in. while others had nominal dimensions of 1.0 in. x 1.0 in.

Sheet A-109 summarizes all of the results for the out-of-plane Poisson's ratio tests (Test 7) conducted at a temperature of -40°F. Individual test results are shown on A-110 to A-114. As shown on Sheet A-109, the out-of-plane Poisson's ratio (ν_{xz} or ν_{yz}) was averaged as 0.174. The results of the five specimens tested indicate significant scatter.

Sheet A-115 summarizes all of the results for the out-of-plane Poisson's ratio tests (Test 7) conducted at ambient temperatures. Individual test results are shown on A-116 to A-120. As shown on Sheet G-1, the out-of-plane Poisson's ratio (ν_{xz} or ν_{yz}) at ambient temperatures was averaged as 0.177. The results of the five specimens tested indicate significant scatter. However,

an average value between 0.17 and 0.18 was fairly consistent during all iterations of the acceptance testing. The average value compares well with the average value at cold temperatures.

Sheet A-121 summarizes all of the results for the out-of-plane Poisson's ratio tests (Test 7) conducted at a temperature of 140°F. Individual test results are shown on A-122 to A-126. As shown on Sheet A-121, the out-of-plane Poisson ratio (ν_{xz} or ν_{yz}) at a temperature of 140°F was averaged as 0.179. The results are fairly consistent with the exception of Specimen MATA-OP-140-1. The average value compares well with the average value at ambient temperatures.

CHAPTER 4: MATERIAL 1-FY08, MATERIAL 4-FY09, AND MATERIAL 5-FY09

This chapter summarizes the results of all composite materials with Applied Poleramic (API) SC-15 Epoxy and S2-Glass Plain Weave (S2 Glass) fibers. According to Table 1.3-1, this includes Material 1-FY08, Material 4-FY09, and Material 5-FY09. Material 1-FY08 has a nominal thickness (t) of 1.5 in., Material 4-FY09 has a nominal thickness (t) of 1.0 in., and Material 5-FY09 has a nominal thickness of 0.75 in. Table 4.0-1 lists the primary material testing results for all three of these materials. More information in regards to the tests performed and results can be found in Appendices B, G, and H, respectively. The results in Table 4.0-1 will be discussed in the following subsections which will refer to the appendices.

Table 4.0-1: Material Testing Results, all API SC-15, S2-Glass Materials

| Test | Property | Material 1-FY08 (t = 1.5 in) | | | Material 4-FY09 (t = 1.0 in) | | | Material 5-FY09 (t = 0.75 in) | | |
|--------------------------|--|---------------------------------|---------|---------|---------------------------------|---------|---------|----------------------------------|---------|---------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y (psi) | 51720 | 48035 | 42203 | 53827 | 49131 | 43236 | 46837 | 45551 | 38130 |
| | E _x or E _y (psi) | 2399400 | 2168333 | 2180534 | 2592766 | 2328807 | 2243374 | 2309264 | 2018540 | 1910698 |
| | ν_{xy} | 0.2503 | 0.2128 | 0.2666 | 0.2568 | 0.2184 | 0.2769 | 0.2422 | 0.2644 | 0.2159 |
| In-Plane Compression | SC _x or SC _y (psi) | 45804 | 40268 | 33235 | 43680 | 35065 | 30672 | 45159 | 32687 | 26120 |
| | EC _x or EC _y (psi) | 2861819 | 2870964 | 2692793 | 2957847 | 3010802 | 2789322 | 2997734 | 2890905 | 2662344 |
| | ν_{Cxy} | 0.312 | 0.325 | 0.319 | 0.263 | 0.257 | 0.25 | 0.261 | 0.256 | 0.276 |
| In-Plane Shear | S _{xy} (psi) | 37620 | 31056 | 27809 | 37942 | 31530 | 25399 | 36915 | 28755 | 22764 |
| | G _{xy} (psi) | 1429514 | 1313712 | 1221689 | 1875351 | 1547881 | 1507830 | 1516312 | 1427879 | 1312227 |
| Out-of-Plane Tension | ST _z (psi) | 5028 | 4347 | 3888 | 1371 | 1481 | 1215 | 4476 | 3947 | 3417 |
| | E _z (psi) | 1465000 | 1424406 | 1106657 | 1639149 | 1603490 | 1291607 | 1272445 | 1248494 | 1034477 |
| Out-of-Plane Compression | SC _z (psi) | 100317 | 80317 | 65994 | 100873 | 79906 | 71303 | 110379 | 88561 | 77668 |
| | EC _z (psi) | 1921878 | 1422605 | 1233110 | 1831220 | 1345276 | 1459822 | 1410032 | 1185088 | 1160739 |
| Out-of-Plane Shear | S _{xz} or S _{yz} (psi) | 4571 | 3804 | 3087 | 3889 | 3913 | 3015 | 4853 | 4215 | 3666 |
| | G _{xz} or G _{yz} (psi) | 837401 | 864066 | 700184 | 1162624 | 1045073 | 779597 | 469174 | 340799 | 306779 |
| OP Poisson | ν_{xz} or ν_{yz} | 0.17 | 0.1847 | 0.1192 | 0.154 | 0.144 | 0.1471 | 0.1297 | 0.1707 | 0.0987 |

4.1 In-Plane Tension

The in-plane tension test results for Material 1-FY08 are shown on B-1 to B-6 for -40°F, B-7 to B-12 for 70°F, and B-13 to B-18 for 140°F. The tensile strength results are 51,720 psi, 48,035 psi, and 42,203 psi, respectively. The elastic modulus results are 2,399,400 psi, 2,168,333 psi, and

2,180,534 psi, respectively. The Poisson ratio results are 0.250, 0.213, and 0.267, respectively. The results indicate that as temperature decreases, the ultimate tensile strength increases. The relationships between elastic modulus and Poisson's ratio vs. temperature are inconclusive for this material.

The in-plane tension test results for Material 4-FY09 are shown on G-1 to G-6 for -40°F, G-7 to G-12 for 70°F, and G-13 to G-18 for 140°F. The tensile strength results are 53,827 psi, 49,131 psi, and 43,236 psi, respectively. The elastic modulus results are 2,592,766 psi, 2,328,807 psi, and 2,243,374 psi, respectively. The Poisson ratio results are 0.257, 0.218, and 0.277, respectively. The results indicate that as temperature decreases, the ultimate tensile strength and the elastic modulus increase. The temperature has no clear influence on the Poisson's ratio results.

The in-plane tension test results for Material 5-FY09 are shown on H-1 to H-6 for -40°F, H-7 to H-12 for 70°F, and H-13 to H-18 for 140°F. The tensile strength results are 46,837 psi, 45,551 psi, and 38,130 psi, respectively. The elastic modulus results are 2,309,264 psi, 2,018,540 psi, and 1,910,698 psi, respectively. The Poisson ratio results are 0.242, 0.264, and 0.216, respectively. The results indicate that as temperature decreases, the ultimate tensile strength and the elastic modulus increase. The temperature has no clear influence on the Poisson's ratio results.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

4.2 In-Plane Compression

The in-plane compression test results for Material 1-FY08 are shown on B-19 to B-24 for -40°F, B-25 to B-30 for 70°F, and B-31 to B-36 for 140°F. The compressive strength results are 45,804 psi, 40,268 psi, and 33,235 psi, respectively. The elastic modulus results are 2,861,819 psi, 2,870,964 psi, and 2,692,793 psi, respectively. The Poisson ratio results are 0.312, 0.325, and 0.319, respectively. The results indicate that as the temperature decreases, the ultimate compressive strength increases significantly. The relationships between elastic modulus and Poisson's ratio vs. temperature are inconclusive for this material.

The in-plane compression test results for Material 4-FY09 are shown on G-19 to G-24 for -40°F, G-25 to G-30 for 70°F, and G-31 to G-36 for 140°F. The compressive strength results are

43,680 psi, 35,065 psi, and 30,672 psi, respectively. The elastic modulus results are 2,957,847 psi, 3,010,802 psi, and 2,789,322 psi, respectively. The Poisson ratio results are 0.263, 0.257, and 0.250, respectively. The results indicate that as the temperature decreases, the ultimate compressive strength increases significantly. The relationships between elastic modulus and Poisson's ratio vs. temperature are inconclusive for this material.

The in-plane compression test results for Material 5-FY09 are shown on H-19 to H-24 for -40°F, H-25 to H-30 for 70°F, and H-31 to H-36 for 140°F. The compressive strength results are 45,159 psi, 32,687 psi, and 26,120 psi, respectively. The elastic modulus results are 2,997,734 psi, 2,890,905 psi, and 2,662,344 psi, respectively. The Poisson ratio results are 0.261, 0.256, and 0.276, respectively. The results indicate that as the temperature decreases, the ultimate compressive strength increases significantly. As the temperature decreases, the elastic modulus increases slightly. The relationship between Poisson's ratio and the test temperature are inconclusive.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature, material thickness, and the direction of load (compression or tension) on the strength and stiffness results.

4.3 In-Plane Shear

The in-plane shear test results for Material 1-FY08 are shown on B-37 to B-42 for -40°F, B-43 to B-48 for 70°F, and B-49 to B-54 for 140°F. The shear strength results are 37,620 psi, 31,056 psi, and 27,809 psi, respectively. The shear modulus results are 1,429,514 psi, 1,313,712 psi, and 1,221,689 psi, respectively.

The in-plane shear test results for Material 4-FY09 are shown on G-37 to G-42 for -40°F, G-43 to G-48 for 70°F, and G-49 to G-54 for 140°F. The shear strength results are 37,942 psi, 31,530 psi, and 25,399 psi, respectively. The shear modulus results are 1,875,351 psi, 1,547,881 psi, and 1,507,830 psi, respectively.

The in-plane shear test results for Material 5-FY09 are shown on H-37 to H-42 for -40°F, H-43 to H-48 for 70°F, and H-49 to H-54 for 140°F. The shear strength results are 36,915 psi, 28,755 psi, and 22,764 psi, respectively. The shear modulus results are 1,516,312 psi, 1,427,879 psi, and

1,312,227 psi, respectively. For all three materials, the results indicate that as the temperature decreases, the shear strength of the material increases significantly and the elastic modulus increases slightly.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

4.4 Out-of-Plane Tension

The out-of-plane tension test results for Material 1-FY08 are shown on B-55 to B-60 for -40°F, B-61 to B-66 for 70°F, and B-67 to B-72 for 140°F. The tensile strength results are 5,028 psi, 4,347 psi, and 3,888 psi, respectively. The elastic modulus results are 1,465,000 psi, 1,424,406 psi, and 1,106,657 psi, respectively. The results indicate that as temperature decreases, the out-of-plane tensile strength and the elastic modulus increase.

The out-of-plane tension test results for Material 4-FY09 are shown on G-55 to G-60 for -40°F, G-61 to G-66 for 70°F, and G-67 to G-72 for 140°F. The tensile strength results are 1,371 psi, 1,481 psi, and 1,215 psi, respectively. The elastic modulus results are 1,639,149 psi, 1,630,490 psi, and 1,291,607 psi, respectively. As indicated by the results in Appendix G, the out-of-plane tension results were somewhat scattered. As shown on page G-67, bondline failure occurred for two specimens at a test temperature of 140°F. However, the failure stress in the reduced test area was comparable to the failure strength of specimens that failed in the reduced test area. The resulting strengths are extremely low in comparison to Material 1-FY08 and Material 5-FY09. This will be discussed in more detail in Chapter 8.

The out-of-plane tension test results for Material 5-FY09 are shown on H-55 to H-60 for -40°F, H-61 to H-66 for 70°F, and H-67 to H-72 for 140°F. The tensile strength results are 4,476 psi, 3,947 psi, and 3,417 psi, respectively. The elastic modulus results are 1,272,445 psi, 1,248,494 psi, and 1,034,477 psi, respectively. The elastic modulus and the ultimate strength both increased slightly with a decrease in temperature.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

4.5 Out-of-Plane Compression

The out-of-plane compression test results for Material 1-FY08 are shown on B-73 to B-78 for -40°F, B-79 to B-84 for 70°F, and B-85 to B-90 for 140°F. The compressive strength results are 100,317 psi, 80,317 psi, and 65,994 psi, respectively. The elastic modulus results are 1,921,878 psi, 1,422,605 psi, and 1,233,110 psi, respectively.

The out-of-plane compression test results for Material 4-FY09 are shown on G-73 to G-78 for -40°F, G-79 to G-84 for 70°F, and G-85 to G-90 for 140°F. The compressive strength results are 100,873 psi, 79,906 psi, and 71,303 psi, respectively. The elastic modulus results are 1,831,220 psi, 1,345,276 psi, and 1,459,822 psi, respectively.

The out-of-plane compression test results for Material 5-FY09 are shown on H-73 to H-78 for -40°F, H-79 to H-84 for 70°F, and H-85 to H-90 for 140°F. The compressive strength results are 110,379 psi, 88,561 psi, and 77,668 psi, respectively. The elastic modulus results are 1,410,032 psi, 1,185,088 psi, and 1,160,739 psi, respectively.

For all three materials, the results indicate that as the temperature decreases, the out-of-plane compressive strength increases significantly. The relationship between temperature and elastic modulus is inconclusive from the results of the three materials. However, the general trend is that elastic modulus increases with a decrease in temperature.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature, material thickness, and the direction of load (compression or tension) on the strength and stiffness results.

4.6 Out-of-Plane Shear

The out-of-plane shear test results for Material 1-FY08 are shown on B-91 to B-96 for -40°F, B-97 to B-102 for 70°F, and B-103 to B-108 for 140°F. The out-of-plane shear strength results are 4,571 psi, 3,804 psi, and 3,087 psi, respectively. The out-of-plane shear modulus results are 837,401 psi, 864,066 psi, and 700,184 psi, respectively. The results indicate that as the temperature decreases, the out-of-plane shear strength increases. However, there is not a direct relationship between the test temperature and the shear modulus.

The out-of-plane shear test results for Material 4-FY09 are shown on G-91 to G-96 for -40°F, G-97 to G-102 for 70°F, and G-103 to G-108 for 140°F. The out-of-plane shear strength results are 3,889 psi, 3,913 psi, and 3,015 psi, respectively. The out-of-plane shear modulus results are 1,162,624 psi, 1,045,073 psi, and 779,597 psi, respectively. The results at -40°F and 70°F are similar. However, both the elastic modulus and the tensile strength decrease significantly at a temperature of 140°F.

The out-of-plane shear test results for Material 5-FY09 are shown on H-91 to H-96 for -40°F, H-97 to H-102 for 70°F, and H-103 to H-108 for 140°F. The out-of-plane shear strength results are 4,853 psi, 4,215 psi, and 3,666 psi, respectively. The out-of-plane shear modulus results are 469,174 psi, 340,799 psi, and 306,779 psi, respectively. Both the elastic modulus and the tensile strength decrease as temperature increases.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

4.7 Out-of-Plane Poisson

The out-of-plane Poisson test results for Material 1-FY08 are shown on B-109 to B-114 for -40°F, B-115 to B-120 for 70°F, and B-121 to B-126 for 140°F. The out-of-plane Poisson's results are 0.170, 0.185, and 0.119, respectively.

The out-of-plane Poisson test results for Material 4-FY09 are shown on G-109 to G-114 for -40°F, G-115 to G-120 for 70°F, and G-121 to G-126 for 140°F. The Poisson's ratios are 0.154, 0.144, and 0.147, respectively.

The out-of-plane Poisson test results for Material 5-FY09 are shown on H-109 to H-114 for -40°F, H-115 to H-120 for 70°F, and H-121 to H-126 for 140°F. The Poisson's ratios are 0.130, 0.171, and 0.099, respectively. For all three materials tested, the results indicate no direct relationship between the out-of-plane Poisson ratios and the test temperatures.

CHAPTER 5: MATERIAL 2-FY08, MATERIAL 1-FY09, AND MATERIAL 2-FY09

This chapter summarizes the results of all composite materials composed of Huntsman PolyUrethane (PU) Rencast 6405 and S2-Glass Plain Weave (S2-Glass) fibers. As shown in Table 1.3-1, this includes Material 2-FY08, Material 1-FY09, and Material 2-FY09. Material 2-FY08 has a nominal thickness (t) of 1.5 in., Material 1-FY09 has a nominal thickness (t) of 1.0 in., and Material 2-FY09 has a nominal thickness (t) of 0.75 in. Table 5.0-1 lists the primary material testing results for all three of these materials. More information in regards to the tests performed and results can be found in Appendices C, D, and E, respectively. The results in Table 5.0-1 will be discussed in the following subsections which refer to the appendices.

Table 5.0-1: Material Testing Results, all Huntsman Rencast 6405, S2-Glass Materials

| Test | Property | Material 2-FY08 ($t = 1.5$ in) | | | Material 1-FY09 ($t = 1.0$ in) | | | Material 2-FY09 ($t = 0.75$ in) | | |
|--------------------------|--|------------------------------------|---------|---------|------------------------------------|---------|---------|-------------------------------------|---------|---------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y (psi) | 54330 | 45226 | 31910 | 51176 | 45188 | 33951 | 45714 | 43257 | 30979 |
| | E _x or E _y (psi) | 2286416 | 1986367 | 1656583 | 2225572 | 2036733 | 1528496 | 2100891 | 1784110 | 1663892 |
| | ν_{xy} | 0.1886 | 0.211 | 0.1765 | 0.2671 | 0.2491 | 0.2677 | 0.2159 | 0.2477 | 0.4277 |
| In-Plane Compression | SC _x or SC _y (psi) | 37486 | 25009 | 12826 | 39116 | 26453 | 11890 | 36806 | 26695 | 10486 |
| | EC _x or EC _y (psi) | 2692235 | 2717877 | 2340062 | 2877581 | 2796012 | 2298234 | 2839855 | 2730500 | 2244152 |
| | ν_{Cxy} | 0.290 | 0.297 | 0.279 | 0.253 | 0.262 | 0.298 | 0.246 | 0.206 | 0.297 |
| In-Plane Shear | S _{xy} (psi) | 23690 | 21685 | 17690 | 30763 | 23625 | 15145 | 28345 | 19104 | 10301 |
| | G _{xy} (psi) | 1241458 | 1280563 | 846113 | 1364919 | 1336103 | 1034024 | 1316192 | 1262899 | 910531 |
| Out-of-Plane Tension | ST _z (psi) | 4970 | 3623 | 1905 | 4604 | 3095 | 1893 | 4477 | 3304 | 1602 |
| | E _z (psi) | 1303324 | 1077525 | 230915 | 1140678 | 931037 | 334720 | 1121661 | 985645 | 264627 |
| Out-of-Plane Compression | SC _z (psi) | 65513 | 56040 | 46393 | 71548 | 57795 | 50439 | 69614 | 51851 | 48680 |
| | EC _z (psi) | 1165695 | 1028310 | 969253 | 1231113 | 1080657 | 1174700 | 1107758 | 805102 | 896758 |
| Out-of-Plane Shear | S _{xz} or S _{yz} (psi) | 5360 | 3064 | 1053 | 4620 | 2720 | 931 | 4780 | 2923 | 1019 |
| | G _{xz} or G _{yz} (psi) | 394355 | 272697 | 20012 | 601889 | 460711 | 19437 | 603574 | 457242 | 43716 |
| OP Poisson | ν_{xz} or ν_{yz} | 0.113 | 0.132 | -0.037 | 0.179 | 0.137 | 0.118 | 0.153 | 0.174 | 0.132 |

5.1 In-Plane Tension

The in-plane tension test results for Material 2-FY08 are shown on C-1 to C-6 for -40°F, C-7 to C-12 for 70°F, and C-13 to C-18 for 140°F. The tensile strength results are 54,330 psi, 45,226 psi,

and 31,910 psi, respectively. The elastic modulus results are 2,286,416 psi, 1,986,367 psi, and 1,656,583 psi, respectively. The Poisson ratio results are 0.189, 0.211, and 0.177, respectively. The results indicate that as temperature decreases, the ultimate tensile strength increases significantly. In addition, as temperature increases, the elastic modulus decreases. The relationship between the Poisson's ratio vs. temperature is inconclusive.

The in-plane tension test results for Material 1-FY09 are shown on D-1 to D-6 for -40°F, D-7 to D-12 for 70°F, and D-13 to D-18 for 140°F. The tensile strength results are 51,176 psi, 45,188 psi, and 33,951 psi, respectively. The elastic modulus results are 2,225,572 psi, 2,036,733 psi, and 1,528,496 psi, respectively. The Poisson's ratio results are 0.267, 0.249, and 0.268, respectively. The elastic modulus and ultimate strength results are very similar to the results of Material 2-FY08. The temperature has no clear influence on the Poisson's ratio results.

The in-plane tension test results for Material 2-FY09 are shown on E-1 to E-6 for -40°F, E-7 to E-12 for 70°F, and E-13 to E-18 for 140°F. The tensile strength results are 45,714 psi, 43,257 psi, and 30,979 psi, respectively. The elastic modulus results are 2,100,891 psi, 1,784,110 psi, and 1,663,892 psi, respectively. The Poisson's ratio results are 0.216, 0.248, and 0.428, respectively. The results indicate that as temperature decreases, the ultimate tensile strength and the elastic modulus increase. The temperature has no clear influence on the Poisson's ratio results. The Poisson's ratio at 140°F is very high in comparison to all other materials discussed in this section. The transverse strain curves found on Pages E-14 to E-18 are not consistent and do not exhibit linear behavior.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

5.2 In-Plane Compression

The in-plane compression test results for Material 2-FY08 are shown on C-19 to C-24 for -40°F, C-25 to C-30 for 70°F, and C-31 to C-36 for 140°F. The compressive strength results are 37,486 psi, 25,009 psi, and 12,826 psi, respectively. The elastic modulus results are 2,692,235 psi, 2,717,877 psi, and 2,340,062 psi, respectively. The Poisson ratio results are 0.290, 0.297, and 0.279, respectively.

The in-plane compression test results for Material 1-FY09 are shown on D-19 to D-24 for -40°F, D-25 to D-30 for 70°F, and D-31 to D-36 for 140°F. The compressive strength results are 39,116 psi, 26,453 psi, and 11,890 psi, respectively. The elastic modulus results are 2,877,581 psi, 2,796,012 psi, and 2,298,234 psi, respectively. The Poisson ratio results are 0.253, 0.262, and 0.298, respectively.

The in-plane compression test results for Material 2-FY09 are shown on E-19 to E-24 for -40°F, E-25 to E-30 for 70°F, and E-31 to E-36 for 140°F. The compressive strength results are 36,806 psi, 26,695 psi, and 10,486 psi, respectively. The elastic modulus results are 2,839,855 psi, 2,730,500 psi, and 2,244,142 psi, respectively. The Poisson ratio results are 0.246, 0.206, and 0.297, respectively.

The ultimate strength of all three of these materials is influenced significantly by temperature. As temperature increases, the ultimate strength decreases. Temperature is not as influential on the elastic modulus. However, for all three materials tested, the lowest compressive elastic modulus was measured at a maximum temperature of 140°F. Direct trends are not found in the Poisson's ratio results which were between 0.2 and 0.3. The results will be discussed further in Chapter 8.

5.3 In-Plane Shear

The in-plane shear test results for Material 2-FY08 are shown on C-37 to C-42 for -40°F, C-43 to C-48 for 70°F, and C-49 to C-54 for 140°F. The shear strength results are 23,690 psi, 21,685 psi, and 17,690 psi, respectively. The shear modulus results are 1,241,458 psi, 1,280,563 psi, and 846,113 psi, respectively.

The in-plane shear test results for Material 1-FY09 are shown on D-37 to D-42 for -40°F, D-43 to D-48 for 70°F, and D-49 to D-54 for 140°F. The shear strength results are 30,763 psi, 23,625 psi, and 15,145 psi, respectively. The shear modulus results are 1,364,919 psi, 1,336,103 psi, and 1,034,024 psi, respectively.

The in-plane shear test results for Material 2-FY09 are shown on E-37 to E-42 for -40°F, E-43 to E-48 for 70°F, and E-49 to E-54 for 140°F. The shear strength results are 28,345 psi, 19,104 psi, and 10,301 psi, respectively. The shear modulus results are 1,316,192 psi, 1,262,899 psi, and 910,531 psi, respectively.

For all three materials, the results indicate that as the temperature decreases, the shear strength of the material increases significantly. The resulting shear modulus at -40°F and 70°F are comparable. However, the shear modulus decreases significantly at a temperature of 140°F. The results will be discussed further in Chapter 8.

5.4 Out-of-Plane Tension

The out-of-plane tension test results for Material 2-FY08 are shown on C-55 to C-60 for -40°F, C-61 to C-66 for 70°F, and C-67 to C-72 for 140°F. The tensile strength results are 4,970 psi, 3,623 psi, and 1,905 psi, respectively. The elastic modulus results are 1,303,324 psi, 1,077,525 psi, and 230,915 psi, respectively. The results indicate that as temperature decreases, the out-of-plane tensile strength and the out-of-plane elastic modulus increase significantly. At a test temperature of 140°F, the ultimate strength is approximately 53% that at ambient temperatures and the elastic modulus is approximately 21% that at ambient temperatures.

The out-of-plane tension test results for Material 1-FY09 are shown on D-55 to D-60 for -40°F, D-61 to D-66 for 70°F, and D-67 to D-72 for 140°F. The tensile strength results are 4,604 psi, 3,095 psi, and 1,893 psi, respectively. The elastic modulus results are 1,140,678 psi, 931,037 psi, and 334,720 psi, respectively. The elastic modulus and the ultimate strength of this material both decrease significantly with an increase in temperature. At a test temperature of 140°F, the ultimate strength is approximately 61% that at ambient temperatures and the elastic modulus is approximately 36% that at ambient temperatures.

The out-of-plane tension test results for Material 2-FY09 are shown on E-55 to E-60 for -40°F, E-61 to E-66 for 70°F, and E-67 to E-72 for 140°F. The tensile strength results are 4,477 psi, 3,304 psi, and 1,602 psi, respectively. The elastic modulus results are 1,121,661 psi, 985,645 psi, and 264,627 psi, respectively. The elastic modulus and the ultimate strength of this material both decrease significantly with an increase in temperature. At a test temperature of 140°F, the ultimate strength is approximately 48% that at ambient temperatures and the elastic modulus is approximately 27% that at ambient temperatures.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature and material thickness on the strength and stiffness results.

5.5 Out-of-Plane Compression

The out-of-plane compression test results for Material 2-FY08 are shown on C-73 to C-78 for -40°F, C-79 to C-84 for 70°F, and C-85 to C-90 for 140°F. The compressive strength results are 65,513 psi, 56,040 psi, and 46,393 psi, respectively. The elastic modulus results are 1,165,695 psi, 1,028,310 psi, and 969,253 psi, respectively. The results indicate that as temperature decreases, the out-of-plane compressive strength and compressive modulus increase.

The out-of-plane compression test results for Material 1-FY09 are shown on D-73 to D-78 for -40°F, D-79 to D-84 for 70°F, and D-85 to D-90 for 140°F. The compressive strength results are 71,548 psi, 57,795 psi, and 50,439 psi, respectively. The elastic modulus results are 1,231,113 psi, 1,080,657 psi, and 1,174,700 psi, respectively. The results indicate that as the temperature decreases, the out-of-plane compressive strength increases slightly from 140°F to 70°F and significantly from 70°F to -40°F. The relationship between elastic modulus and temperature is inconclusive for this material.

The out-of-plane compression test results for Material 2-FY09 are shown on E-73 to E-78 for -40°F, E-79 to E-84 for 70°F, and E-85 to E-90 for 140°F. The compressive strength results are 69,614 psi, 51,851 psi, and 48,680 psi, respectively. The elastic modulus results are 1,107,758 psi, 805,102 psi, and 896,758 psi, respectively. The results are very similar to the results of Material 1-FY09. The results indicate that as the temperature decreases, the out-of-plane compressive strength increases slightly from 140°F to 70°F and significantly from 70°F to -40°F. The relationship between elastic modulus and temperature is inconclusive for this material.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature, material thickness, and the direction of load (compression or tension) on the strength and stiffness results.

5.6 Out-of-Plane Shear

The out-of-plane shear test results for Material 2-FY08 are shown on C-91 to C-96 for -40°F, C-97 to C-102 for 70°F, and C-103 to C-108 for 140°F. The out-of-plane shear strength results are 5,360 psi, 3,064 psi, and 1,053 psi, respectively. The shear modulus results are 394,355 psi, 272,697 psi, and 20,012 psi, respectively. At a test temperature of 140°F, the out-of-plane shear

strength is equal to 34% that at ambient and the out-of-plane shear modulus is equal to 7% that at ambient which is a very significant decrease.

The out-of-plane shear test results for Material 1-FY09 are shown on D-91 to D-96 for -40°F, D-97 to D-102 for 70°F, and D-103 to D-108 for 140°F. The shear strength results are 4,620 psi, 2,720 psi, and 931 psi, respectively. The shear modulus results are 601,889 psi, 460,711 psi, and 19,347 psi, respectively. At a test temperature of 140°F, the out-of-plane shear strength is equal to 34% of that at ambient and the out-of-plane shear modulus is equal to 4% that at ambient.

The out-of-plane shear test results for Material 2-FY09 are shown on E-91 to E-96 for -40°F, E-97 to E-102 for 70°F, and E-103 to E-108 for 140°F. The shear strength results are 4,780 psi, 2,923 psi, and 1,019 psi, respectively. The shear modulus results are 603,574 psi, 457,242 psi, and 43,716 psi, respectively. At a test temperature of 140°F, the out-of-plane shear strength is equal to 35% of that at ambient and the out-of-plane shear modulus is equal to 10% that at ambient. The comparisons are similar to the comparisons made for Material 2-FY08 and Material 1-FY09.

For all three materials, the results at high temperatures are extremely low in comparison to the results obtained at ambient temperatures. The results will be discussed further in Chapter 8.

5.7 Out-of-Plane Poisson

The out-of-plane Poisson's ratio results for Material 2-FY08 are shown on C-109 to C-114 for -40°F, C-115 to C-120 for 70°F, and C-121 to C-126 for 140°F. The out-of-plane Poisson's results are 0.113, 0.132, and -0.037, respectively.

The out-of-plane Poisson's ratio results for Material 1-FY09 are shown on D-109 to D-114 for -40°F, D-115 to D-120 for 70°F, and D-121 to D-126 for 140°F. The Poisson's ratios are 0.179, 0.137, and 0.118, respectively.

The out-of-plane Poisson's ratio results for Material 2-FY09 are shown on E-109 to E-114 for -40°F, E-115 to E-120 for 70°F, and E-121 to E-126 for 140°F. The Poisson's ratios are 0.153, 0.174, and 0.132, respectively.

As mentioned in Section 5.7.1, the Poisson's ratio tests for this material composition were cumbersome to perform at a test temperature of 140°F.

CHAPTER 6: MATERIAL 3-FY09, 3D HYBRID PANELS

This chapter summarizes the results from the material testing of Material 3-FY09. This material is a 0.75 in. thick 3D hybrid panel with a modified orthogonal weave. S2-glass fibers are oriented within the assumed x-y plane and aramid fibers are oriented along the z-axis. Table 6.0-1 lists the primary material testing results. More information in regards to the tests performed and results can be found in Appendix F. The results in Table 6.0-1 will be discussed in the following subsections which will refer to the test data in Appendix F.

Table 6.0-1: Material Testing Results, Material 3-FY09, 3D Weave

| Test | Property | Material 3-FY09 | | |
|--------------------------|----------------------------|-----------------|---------|---------|
| | | -40°F | 70°F | 140°F |
| In-Plane Tension | ST_x or ST_y (psi) | 94461 | 83782 | 76055 |
| | E_x or E_y (psi) | 2923745 | 3061313 | 2939730 |
| | ν_{xy} | 0.070 | 0.063 | 0.058 |
| In-Plane Compression | SC_x or SC_y (psi) | 68346 | 45645 | 34665 |
| | EC_x or EC_y (psi) | 3786027 | 3463579 | 3463828 |
| | νC_{xy} | 0.061 | 0.076 | UD |
| In-Plane Shear | S_{xy} (psi) | 27593 | 23339 | 20339 |
| | G_{xy} (psi) | 516117 | 415404 | 268588 |
| Out-of-Plane Tension | ST_z (psi) | 7742 | 6982 | 5373 |
| | E_z (psi) | 1771241 | 1604104 | 924527 |
| Out-of-Plane Compression | SC_z (psi) | 99424 | 75713 | 61033 |
| | EC_z (psi) | 1471525 | 1152591 | 945082 |
| Out-of-Plane Shear | S_{xz} or S_{yz} (psi) | 6373 | 4281 | 3389 |
| | G_{xz} or G_{yz} (psi) | 406384 | 339945 | 213580 |
| OP Poisson | ν_{xz} or ν_{yz} | 0.104 | 0.127 | 0.075 |

6.1 In-Plane Tension

The in-plane tension test results for Material 3-FY09 are shown on F-1 to F-6 for -40°F, F-7 to F-12 for 70°F, and F-13 to F-18 for 140°F. The tensile strength results are 94,461 psi, 83,782 psi, and 76,055 psi, respectively. The elastic modulus results are 2,923,745 psi, 3,061,313 psi, and

2,939,730 psi, respectively. The Poisson ratio results are 0.070, 0.063, and 0.058, respectively. The results indicate that as temperature decreases, the ultimate tensile strength increases significantly. There is no direct trend between the test temperature and the elastic modulus. The elastic modulus results are similar at all three test temperatures. The results also indicate that as temperature increases, the Poisson's ratio decreases. The results will be discussed further in Chapter 8.

6.2 In-Plane Compression

The in-plane compression test results for Material 3-FY09 are shown on F-19 to F-24 for -40°F, F-25 to F-30 for 70°F, and F-31 to F-36 for 140°F. The compressive strength results are 68,346 psi, 45,645 psi, and 34,665 psi, respectively. The elastic modulus results are 3,786,027 psi, 3,463,579 psi, and 3,463,828 psi, respectively.

The ultimate compressive strength is influenced significantly by temperature. As temperature increases, the ultimate strength decreases. Temperature is not influential on the elastic modulus. The elastic modulus results at all three temperatures are fairly consistent.

6.3 In-Plane Shear

The in-plane shear test results for Material 3-FY09 are shown on F-37 to F-42 for -40°F, F-43 to F-48 for 70°F, and F-49 to F-54 for 140°F. The shear strength results are 27,593 psi, 23,339 psi, and 20,339 psi, respectively. The shear modulus results are 516,117 psi, 415,404 psi, and 268,588 psi, respectively. The results indicate that as the temperature decreases, the shear strength and shear modulus of the material increases. The results will be discussed further in Chapter 8.

6.4 Out-of-Plane Tension

The out-of-plane tension test results for Material 3-FY09 are shown on F-55 to F-66 for -40°F, F-67 to F-78 for 70°F, and F-79 to F-90 for 140°F. The tensile strength results are 7,742 psi, 6,982 psi, and 5,373 psi, respectively. The elastic modulus results are 1,771,241 psi, 1,604,104 psi, and 924,527 psi, respectively. The results indicate that as temperature decreases, the out-of-plane tensile strength and elastic modulus increase. The influence of temperature is more significant on

the elastic modulus results especially when comparing the results at 70°F and 140°F. The results will be discussed in more detail in Chapter 8.

6.5 Out-of-Plane Compression

The out-of-plane compression test results for Material 3-FY09 are shown on F-91 to F-96 for -40°F, F-97 to F-102 for 70°F, and F-103 to F-108 for 140°F. The compressive strength results are 99,424 psi, 75,713 psi, and 61,033 psi, respectively. The elastic modulus results are 1,471,525 psi, 1,152,591 psi, and 945,082 psi, respectively. The results indicate that as temperature decreases, the out-of-plane compressive strength and compressive modulus increase significantly.

The results will be discussed further in Chapter 8. The discussion will include the influence of temperature, material thickness, and the direction of load (compression or tension) on the strength and stiffness results.

6.6 Out-of-Plane Shear

The out-of-plane shear test results for Material 3-FY09 are shown on F-109 to F-114 for -40°F, F-115 to F-120 for 70°F, and F-121 to F-126 for 140°F. The out-of-plane shear strength results are 6,273 psi, 4,281 psi, and 3,389 psi, respectively. The shear modulus results are 406,384 psi, 339,945 psi, and 213,580 psi, respectively. The results indicate that as the temperature decreases, the out-of-plane shear strength and the out-of-plane shear modulus of the material increases. The results will be discussed further in Chapter 8.

6.7 Out-of-Plane Poisson

The out-of-plane Poisson test results for Material 3-FY09 are shown on F-127 to F-132 for -40°F, F-133 to F-138 for 70°F, and F-139 to F-144 for 140°F. The out-of-plane Poisson's results are 0.104, 0.127, and 0.075, respectively. The results show no direct trend between the test temperature and the resulting out-of-plane Poisson's ratio.

CHAPTER 7: MATERIAL 6-FY09, DUCTILE HYBRID FABRIC

This chapter summarizes the results from the material testing of Material 6-FY09. This material is 0.75 in. thick, contains Huntsman PolyUrethane (PU) Rencast 6405, and is reinforced with ductile hybrid fabric (DHF) which was discussed in Section 1.3.3. Table 7.0-1 lists the primary material testing results for the properties identified in Table 1.3-2. More information in regards to the tests performed and results can be found in Appendix I. The results in Table 7.0-1 will be discussed in the following subsections.

Table 7.0-1: Material Testing Results, Material 6-FY09, Ductile Hybrid Fabric

| Test | Property | Material 6-FY09 | | |
|--------------------------|--|-----------------|---------|---------|
| | | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y (psi) | 59658 | 44896 | 35317 |
| | E _x or E _y (psi) | 6630993 | 6812287 | 5666334 |
| | v _{xy} | 0.562 | 0.623 | 0.888 |
| In-Plane Compression | SC _x or SC _y (psi) | 41637 | 27485 | 12922 |
| | EC _x or EC _y (psi) | 4367710 | 5474333 | 5593651 |
| | vC _{xy} | 0.360 | 0.388 | 0.400 |
| In-Plane Shear | S _{xy} (psi) | 24005 | 18541 | 11769 |
| | G _{xy} (psi) | 1931198 | 1954070 | 1567885 |
| Out-of-Plane Tensile | ST _z (psi) | 3206 | 3184 | 1601 |
| | E _z (psi) | 1085445 | 975756 | 370642 |
| Out-of-Plane Compression | SC _z (psi) | 46546 | 35111 | 27001 |
| | EC _z (psi) | 1081349 | 935208 | 799320 |
| Out-of-Plane Shear | S _{xz} or S _{yz} (psi) | 5052 | 3400 | 1417 |
| | G _{xz} or G _{yz} (psi) | 362312 | 273895 | 79668 |
| OP Poisson | v _{xz} | 0.052 | 0.002 | -0.082 |
| | v _{yz} | 0.208 | 0.268 | 0.321 |

7.1 In-Plane Tension

The in-plane tension test results for Material 6-FY09 are shown on I-1 to I-6 for -40°F, I-7 to I-12 for 70°F, and I-13 to I-18 for 140°F. The tensile strength results are 59,658 psi, 44,896 psi, and

35,317 psi, respectively. The elastic modulus results are 6,630,993 psi, 6,812,287 psi, and 5,666,334 psi, respectively. The Poisson ratio results are 0.562, 0.623, and 0.888, respectively. The results indicate that as temperature decreases, the ultimate tensile strength increases significantly. There is no direct relationship between the test temperature and the elastic modulus. The results indicate the following about the Poisson's ratio:

- The in-plane Poisson's ratio is much higher for this material in comparison to all materials with S2-glass fibers
- The in-plane Poisson's ratio increases with an increase in temperature.

7.2 In-Plane Compression

The in-plane compression test results for Material 6-FY09 are shown on I-19 to I-24 for -40°F, I-25 to I-30 for 70°F, and I-31 to I-36 for 140°F. The compressive strength results are 41,637 psi, 27,485 psi, and 12,922 psi, respectively. The elastic modulus results are 4,367,710 psi, 5,474,333 psi, and 5,593,651 psi, respectively. The Poisson ratio results are 0.360, 0.388, and 0.400, respectively.

The ultimate strength is influenced significantly by temperature. As temperature increases, the ultimate strength decreases. The elastic modulus increased with an increase in temperature which is irregular in comparison to all other materials tested part of this research. As temperature increases, the Poisson's ratio increases slightly.

7.3 In-Plane Shear

The in-plane shear test results for Material 6-FY09 are shown on I-37 to I-42 for -40°F, I-43 to I-48 for 70°F, and I-49 to I-54 for 140°F. The shear strength results are 24,005 psi, 18,541 psi, and 11,769 psi, respectively. The shear modulus results are 1,931,198 psi, 1,954,070 psi, and 1,567,885 psi, respectively.

The results indicate that as the temperature decreases, the shear strength of the material increases significantly. The resulting shear modulus at -40°F and 70°F are comparable. However, the shear modulus decreases at a temperature of 140°F.

7.4 Out-of-Plane Tension

The out-of-plane tension test results for Material 6-FY09 are shown on I-55 to I-60 for -40°F, I-61 to I-66 for 70°F, and I-67 to I-72 for 140°F. The tensile strength results are 3,206 psi, 3,184 psi, and 1,601 psi, respectively. The elastic modulus results are 1,085,445 psi, 975,756 psi, and 370,642 psi, respectively. The elastic modulus and ultimate strength results are comparable at -40°F and 70°F. However, both properties decrease significantly at a test temperature of 140°F.

7.5 Out-of-Plane Compression

The out-of-plane compression test results for Material 6-FY09 are shown on I-73 to I-78 for -40°F, I-79 to I-84 for 70°F, and I-85 to I-90 for 140°F. The compressive strength results are 46,546 psi, 35,111 psi, and 27,001 psi, respectively. The elastic modulus results are 1,081,349 psi, 935,208 psi, and 799,320 psi, respectively. The results indicate that as temperature decreases, the out-of-plane compressive strength and compressive modulus increase significantly.

7.6 Out-of-Plane Shear

The out-of-plane shear test results for Material 6-FY09 are shown on I-91 to I-96 for -40°F, I-97 to I-102 for 70°F, and I-103 to I-108 for 140°F. The out-of-plane shear strength results are 5,052 psi, 3,400 psi, and 1,417 psi, respectively. The shear modulus results are 362,312 psi, 273,895 psi, and 79,668 psi, respectively. The results indicate that as the temperature decreases, the out-of-plane shear strength and out-of-plane shear modulus of the material increases. In comparison to the results obtained at ambient temperatures, both results are very low at a temperature of 140°F.

7.7 Out-of-Plane Poisson

The out-of-plane Poisson's ratio test results for Material 6-FY09 are shown on I-109 to I-114 for -40°F, I-115 to I-120 for 70°F, and I-121 to I-126 for 140°F. The out-of-plane Poisson's ratio results for the value ν_{xz} are 0.052, 0.002, and -0.082 respectively. The results indicate minimal strain with respect to the x-direction. For specimens subjected to hot temperatures, the results are negative indicating expansion. Further studies need to be performed to determine the cause of this result such as finite element modeling or individual studies on the fabric itself. However, the overall results of the transverse strains along the x-axis are fairly small. It is evident from the

results that high-modulus carbon fibers do not contract significantly when load is applied along the z-axis.

The out-of-plane Poisson's ratio results for the value ν_{yz} are 0.208, 0.268, and 0.321 respectively. These results are more characteristic in comparison to the other composite materials tested in this research. The results indicate that as temperature increases, the out-of-plane Poisson's ratio ν_{yz} increases. However, as temperature increases, the out-of-plane Poisson's ratio ν_{xz} decreases.

CHAPTER 8: DISCUSSION OF RESULTS

In this chapter, the results presented in Chapters 4-7 will be discussed and parameters that are part of this research will be evaluated. For instance, composite material compositions will be compared and discussed using the results of Material 2-FY09, Material 3-FY09, Material 5-FY09, and Material 6-FY09 which are all 0.75 in. thick materials. Comparisons will also be made to investigate the effects of thickness, temperature, and direction of load on the results. This chapter will also provide a discussion of the variability in the material testing results and what measurements have poor statistical results.

Several graphs are presented in this chapter in which the results are normalized to allow several material testing results to be compared on the same graph. The values that the results are normalized to are noted in the following subsections.

Note that due to the irregular out-of-plane Poisson's results of Material 6-FY09, only the v_{yz} data is included when developing the figures presented in this chapter. The v_{xz} data is not considered. The v_{yz} results are higher and more comparable to the results of other composite materials.

8.1 Temperature Effects

This section evaluates the influence of temperature on the material properties. These comparisons have been introduced in Chapters 4-7. Several graphs are presented, one for each critical property including strength, stiffness, and Poisson's ratio. All materials are used for this study and therefore, each individual result shown in Tables 4.0-1, 5.0-1, 6.0-1, and 7.0-1 are presented as normalized values within this section.

The normalized material testing results at all three temperatures are normalized to the material testing results obtained at an ambient temperature of 70°F. Therefore, the values corresponding to 70°F are always equal to 1.0.

8.1.1 Strength Comparisons

Figure 8.1-1 shows the normalized in-plane tensile strength results. The results in Figure 8.1-1 indicate that for all materials tested, the in-plane tensile strength increases as the nominal test

temperature decreases. This is a valid conclusion for all materials tested and the trends are consistent for a decrease in temperature from 70°F to -40°F and from 140°F to 70°F. The material with the highest increase at -40°F was Material 6-FY09 which consists of Huntsman PU Rencast 6405 (Rencast 6405) and ductile hybrid fabric (DHF). The material with the second highest increase at a temperature of -40°F was Material 2-FY08 which consists of Rencast 6405 and S2-glass. Overall, the tensile strength of all materials with Rencast 6405 is influenced more significantly by temperature. For materials with API SC-15 epoxy, the tensile strength decreases by as much as 16% at temperatures at 140°F (Material 5-FY09). For materials with Rencast 6405, the tensile strength decreases by as much as 31% at temperatures of 140°F (Material 2-FY08). Overall, the results are more favorable for materials with SC-15 epoxy since the tensile strength is more consistent under a range of temperatures.

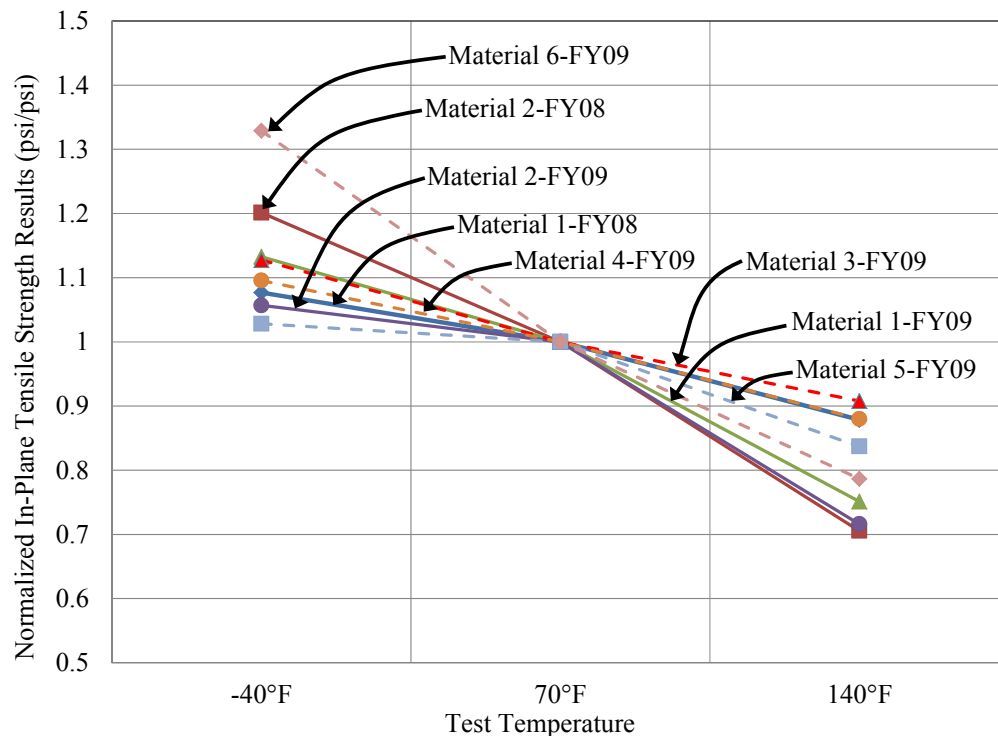


Figure 8.1-1: Effects of Temperature on In-Plane Tensile Strength (ST_x)

Figure 8.1-2 shows the normalized in-plane compressive strength results. The results indicate that the in-plane compressive strength increases as the test temperature decreases. This is a valid conclusion for all materials tested and the trends are consistent for a decrease in temperature from

70°F to -40°F and from 140°F to 70°F. Figure 8.1-2 also indicates that the four materials with Rencast 6405 are influenced more significantly by the test temperature. At -40°F, the compressive strength is as high as 150% of that at ambient temperatures and at 140°F, the compressive strength is as low as 40% of that at ambient temperatures. The influence of temperature is more significant for the in-plane compressive strength as opposed to the in-plane tensile strength. For the materials with SC-15 epoxy, the strength at 140°F is usually within 25% that at ambient temperatures.

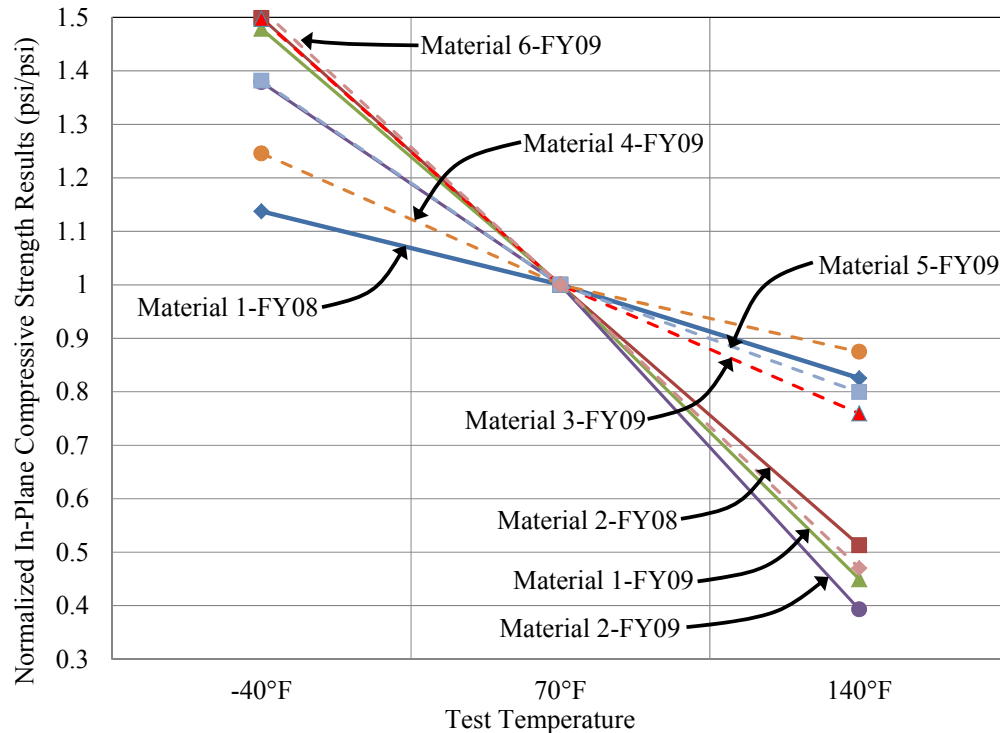


Figure 8.1-2: Effects of Temperature on In-Plane Compressive Strength (SC_x)

Figure 8.1-3 shows the normalized in-plane shear strength results. The influence of temperature is similar to that found for in-plane tension and in-plane compression. The in-plane shear strength increases with a decrease in test temperature. Three of the four materials with Recast 6405 showed significant reductions in in-plane shear strength at 140°F (Material 1-FY09, Material 2-FY09, and Material 6-FY09). In addition, these three materials showed the highest increase in in-plane shear strength at a temperature of -40°F. The in-plane shear strengths for materials with SC-15 epoxy at 140°F and -40°F are typically within 20% of that at ambient temperatures (exception; increase in strength of 28% for Material 5-FY09 at -40°F).

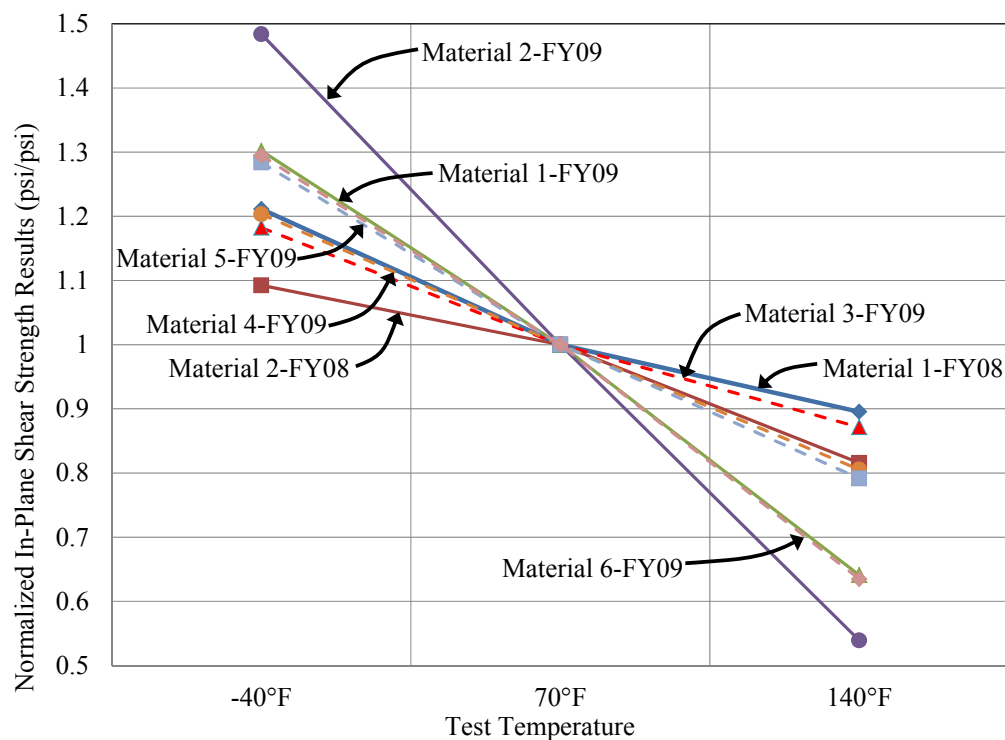


Figure 8.1-3: Effects of Temperature on In-Plane Shear Strength (S_{xy})

Figure 8.1-4 shows the normalized out-of-plane tension strength results. The influence of temperature on the out-of-plane tension strength is similar to that for the in-plane tension strength with some exceptions. In general, as temperature increases, the tensile strength decreases. For Material 6-FY09, the out-of-plane tensile strength at -40°F is comparable to the out-of-plane tension strength at 70°F. For Material 4-FY09, the out-of-plane tension strength is lower at -40°F. However, as discussed in more detail in Section 8.2.2, the out-of-plane tension results of this material were irregular. The strength is much lower than other materials with SC-15 epoxy and S2-Glass.

The out-of-plane tensile strengths for materials with SC-15 epoxy at -40°F and 140°F are usually within 20% that at ambient temperatures. The only exception was for Material 3-FY09 where the out-of-plane tensile strength at 140°F was 77% that at ambient. The out-of-plane tension strength for materials with Rencast 6405 at -40°F is as much as 50% higher than at ambient. The out-of-plane tension strength for materials with Rencast 6405 at 140°F is as much as 50% lower than that at ambient.

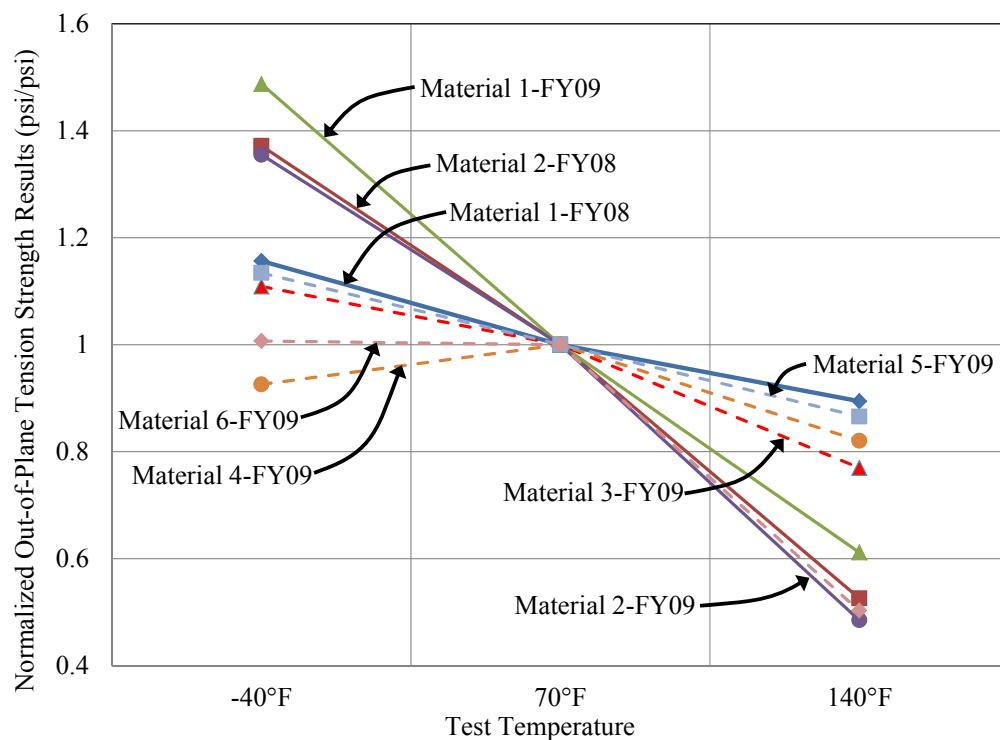


Figure 8.1-4: Effects of Temperature on Out-of-Plane Tensile Strength (ST_z)

Figure 8.1-5 shows the normalized out-of-plane compressive strength results. The influence of temperature on the out-of-plane compressive strength is not as significant as that for other material properties measured in this research. In addition, the resin system does not appear to have a significant influence on the comparisons. The out-of-plane compressive strength of Material 6-FY09 is influenced the most by temperature. The out-of-plane compressive strengths for all materials at 140°F are always within 25% that at ambient temperatures.

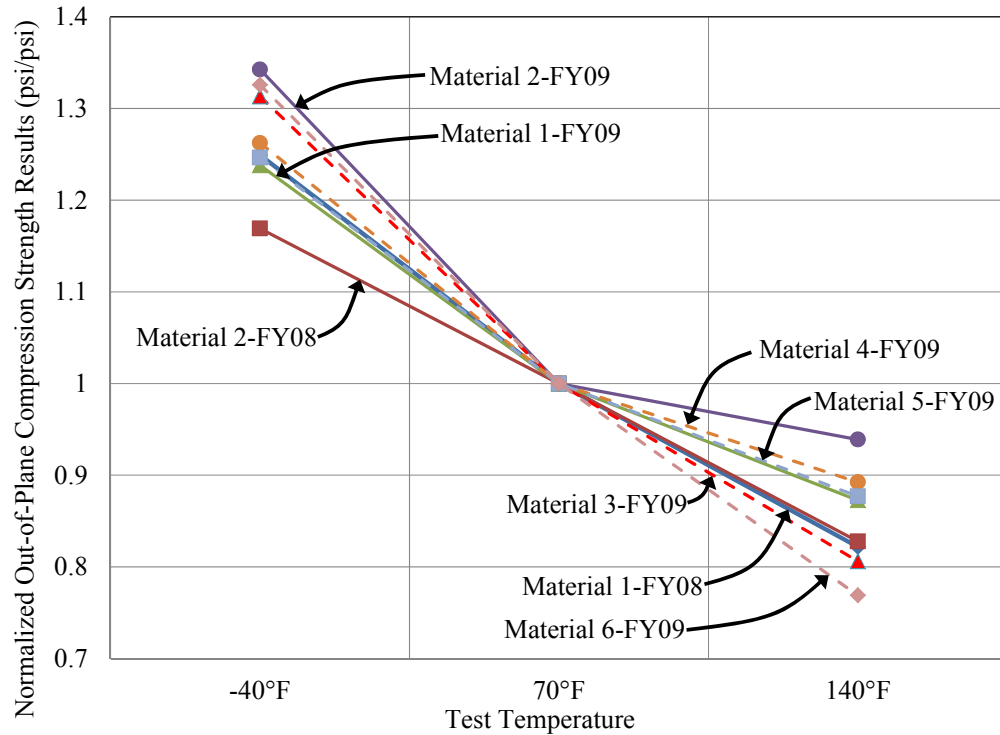


Figure 8.1-5: Effects of Temperature on Out-of-Plane Compressive Strength (SC_z)

Figure 8.1-6 shows the normalized out-of-plane shear strength results. The results indicate a significant decrease in out-of-plane shear strength at a temperature of 140°F for materials with Rencast 6405. At 140°F, the out-of-plane shear strengths are approximately 40% that at ambient. At -40°F, the out-of-plane shear strength increases 50% to 70%.

The out-of-plane shear strengths for materials with SC-15 epoxy at -40°F and 140°F are usually within 22% that at ambient temperatures. However, the strength of Material 3-FY09 increased by 49% at a temperature of -40°F.

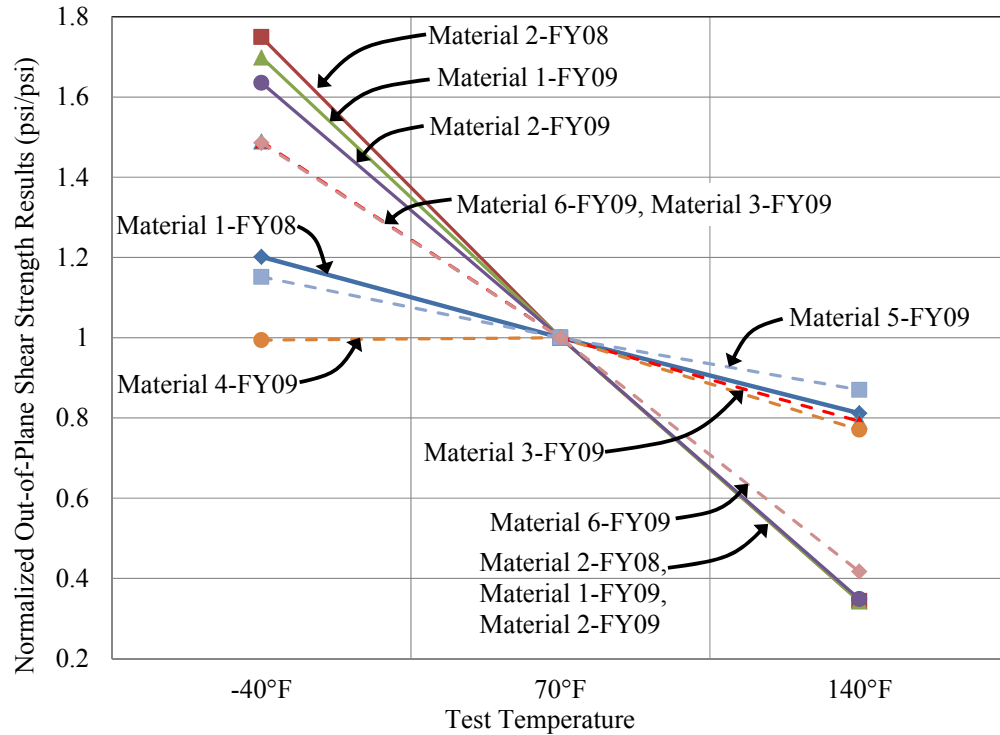


Figure 8.1-6: Effects of Temperature on Out-of-Plane Shear Strength (S_{xz})

8.1.2 Elastic Comparisons

Figure 8.1-7 shows the normalized in-plane tensile elastic modulus results. The results indicate that the in-plane tensile modulus is not as influenced by temperature as the in-plane tensile strength (ref. Figure 8.1-1). In general, the stiffness of the composite materials increases with a decrease in temperature. However, the results at -40°F and 140°F are generally within 20% that at ambient temperatures. At 140°F, the in-plane tensile modulus of Material 1-FY09 decreased by 25%. For Material 3-FY09 and Material 6-FY09, the elastic modulus decreased at -40°F in comparison to that at 70°F. However, the results at the two temperatures are comparable. The in-plane tensile modulus of materials with Rencast 6405 is influenced more significantly by temperature.

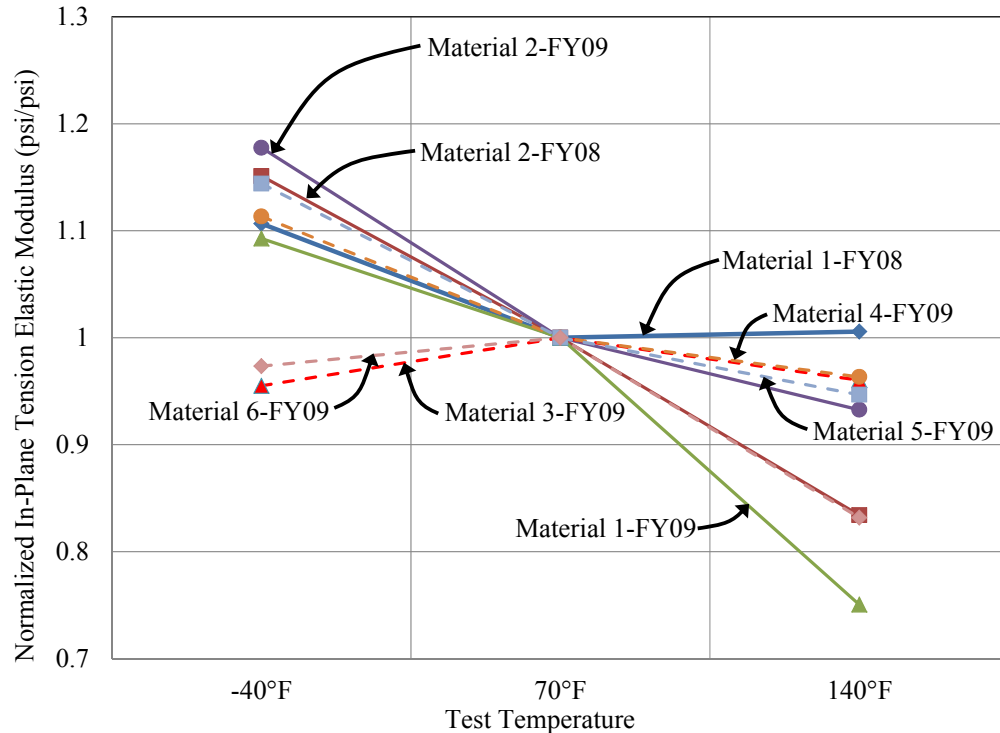


Figure 8.1-7: Effects of Temperature on In-Plane Tensile Elastic Modulus (E_x)

Figure 8.1-8 shows the normalized in-plane compressive elastic modulus results. The general trends in the results indicate that the in-plane compressive modulus decreases with an increase in temperature. However, there are several exceptions in the results. The results of Material 6-FY09 at a temperature of -40°F are irregular. There is a decrease in the compressive modulus of about 20% when compared to the results at ambient.

In general, hot temperatures cause a decrease in the compressive modulus. At a temperature of 140°F, all three results for materials with Rencast 6405 and S2-Glass are comparable and all three results for materials with SC-15 epoxy and S2-Glass are comparable. For these six materials, the in-plane compressive modulus at high temperatures is within 20% of the result at ambient temperatures. The results for Material 3-FY09 and Material 6-FY09 at 140°F are irregular.

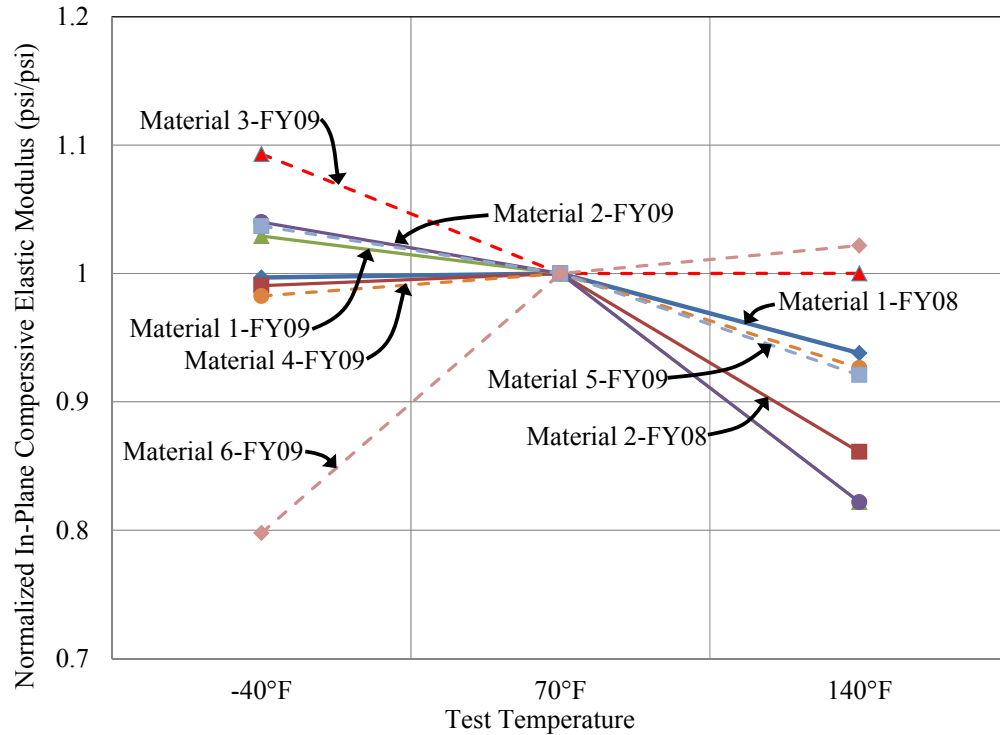


Figure 8.1-8: Effects of Temperature on In-Plane Compressive Elastic Modulus (EC_x)

Figure 8.1-9 shows the normalized in-plane shear modulus results. The results indicate that the in-plane shear modulus increases with a decrease in temperature. However, there is a slight decrease in the in-plane shear modulus for Material 2-FY08 and Material 6-FY09 at a temperature of -40°F. The in-plane shear modulus at -40°F and 140°F is always within 20% of that at ambient for materials with SC-15 epoxy and S2-Glass. For other materials, the differences are as high as 35%. The in-plane shear modulus of Material 3-FY09 is influenced by temperature more than any other material which is an irregular comparison in this research.

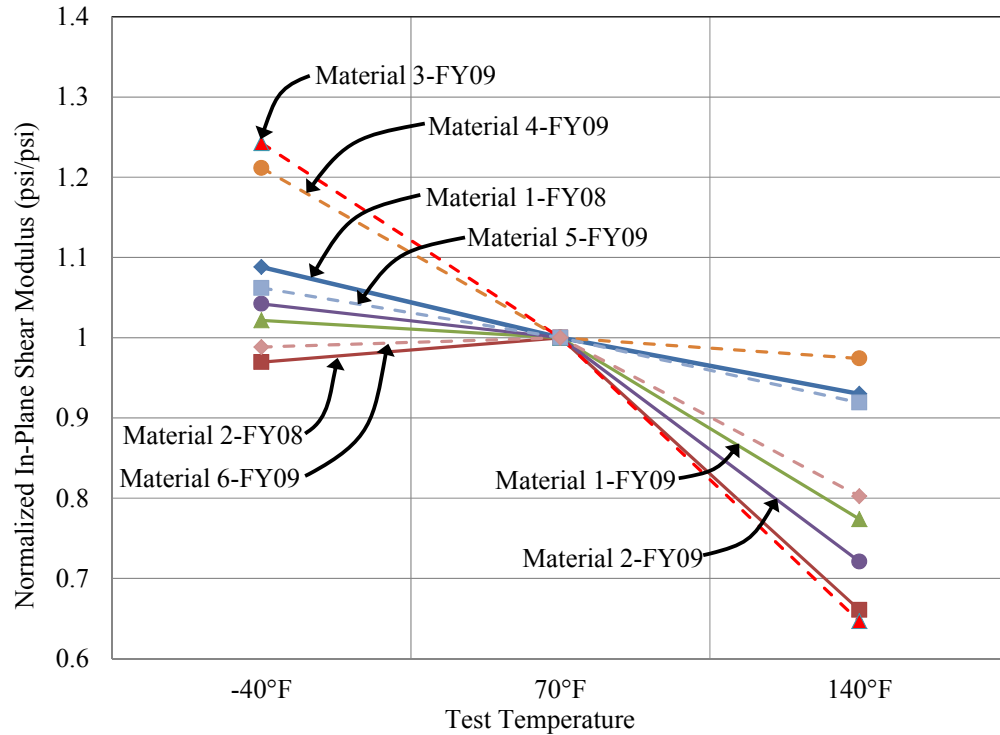


Figure 8.1-9: Effects of Temperature on In-Plane Shear Modulus (G_{xy})

Figure 8.1-10 shows the normalized out-of-plane tensile elastic modulus results. The results clearly indicate that the out-of-plane tensile modulus increases with a decrease in temperature. For all materials with SC-15 epoxy and S2-Glass, the results at -40°F are comparable to the results at 70°F and the results at 140°F are within 22% of that at 70°F. For materials with Rencast 6405, the out-of-plane tension strength increases by as much as 22% at a temperature of -40°F and decreases by as much as 79% at a temperature of 140°F.

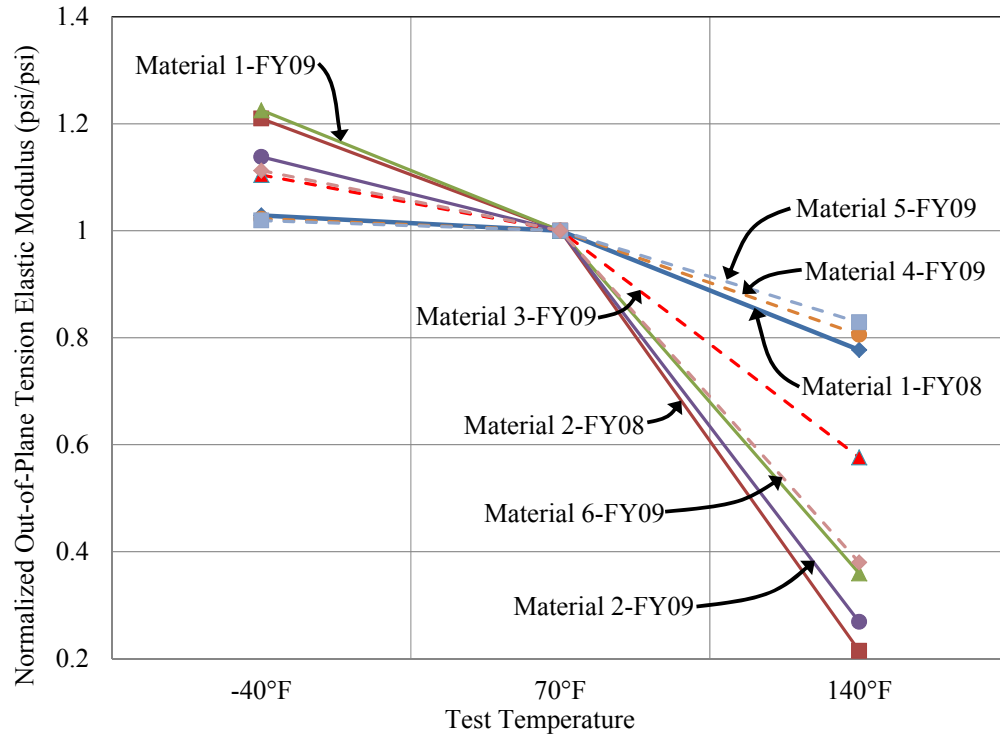


Figure 8.1-10: Effects of Temperature on Out-of-Plane Tensile Elastic Modulus (E_z)

Figure 8.1-11 shows the normalized out-of-plane compressive elastic modulus results. The results in Figure 8.1-11 show no direct influence of the material composition on the out-of-plane compressive results under various temperatures. The results indicate that the out-of-plane compressive modulus decreases by no more than 20% at 140°F for all materials. The out-of-plane compressive modulus of three materials increased at a temperature of 140°F which is an unexpected result. At a temperature of -40°F, the out-of-plane compressive modulus increases between 13% and 37%. Overall, the out-of-plane compressive strength and stiffness properties of composite materials are more consistent than other properties at high and low temperatures.

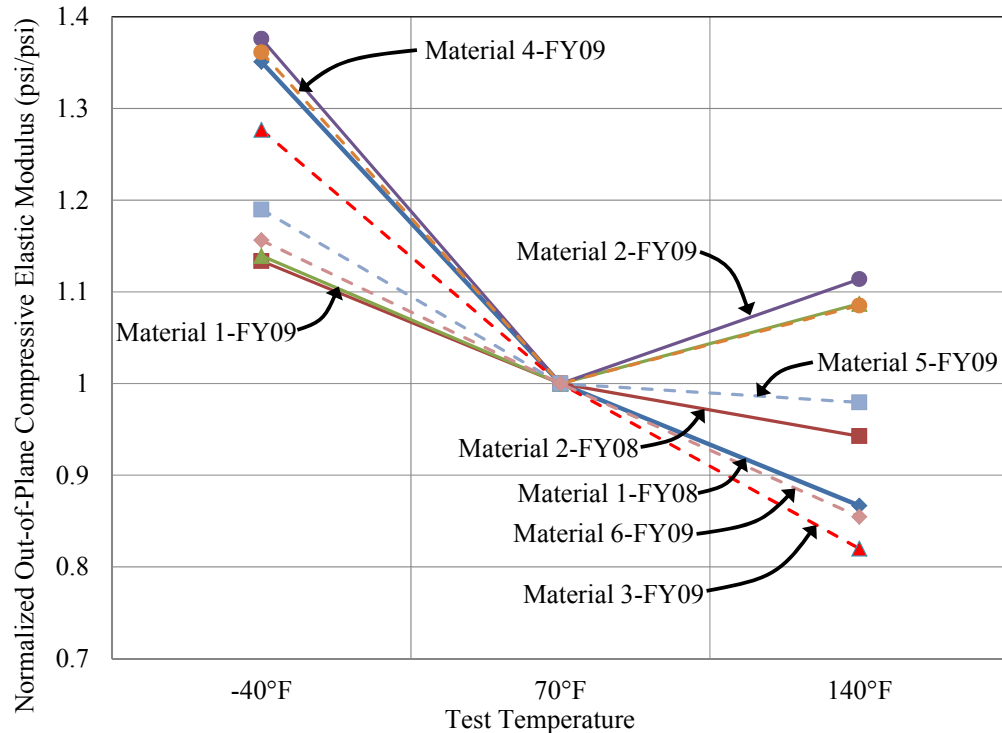


Figure 8.1-11: Effects of Temperature on Out-of-Plane Compressive Elastic Modulus (EC_z)

Figure 8.1-12 shows the normalized out-of-plane shear modulus results. The results indicate that as temperatures increase, the out-of-plane shear modulus decreases. However, the out-of-plane shear modulus of Material 1-FY08 decreased slightly at -40°F in comparisons to the result at 70°F. At a temperature of -40°F, there is no direct trend in the material composition (meaning similar compositions but with different thickness) and the resulting out-of-plane shear results. The modulus increases as much as 45%.

At a temperature of 140°F, the out-of-plane shear modulus of materials with SC-15 epoxy and S2-Glass is within 25% of that at ambient. Material 3-FY09 performs less favorable than other materials with SC-15 epoxy.

The out-of-plane shear modulus results for materials with Rencast 6405 at a temperature of 140°F are much lower than the results at 70°F. The results at 140°F are as low as 4% that at ambient which is unfavorable if this material is exposed to elevated temperatures.

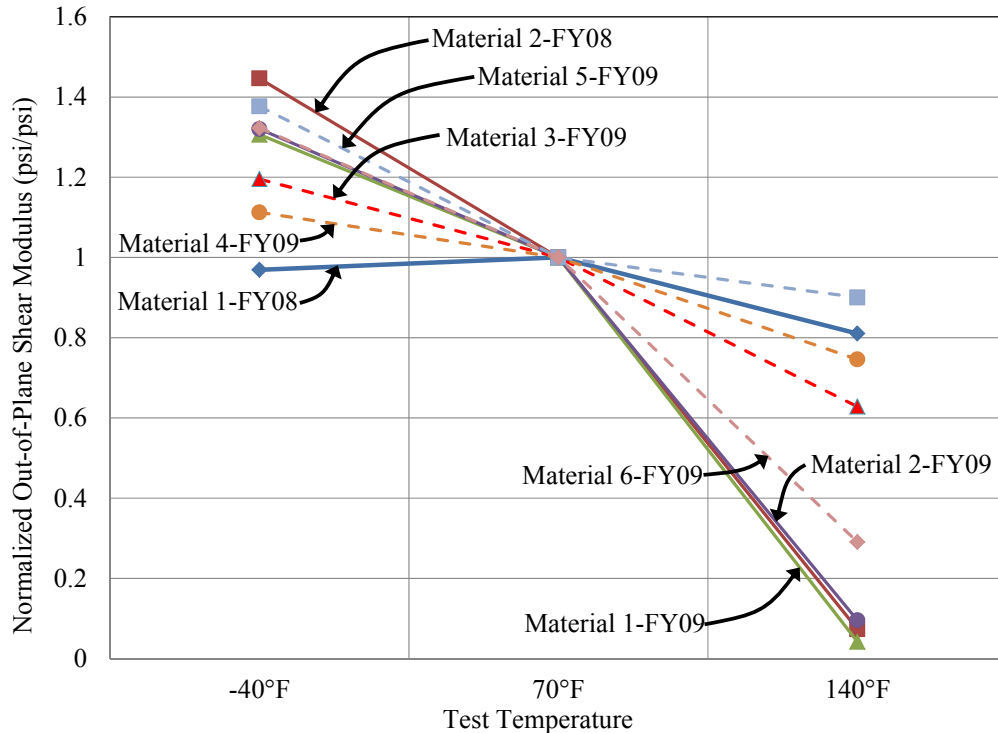


Figure 8.1-12: Effects of Temperature on Out-of-Plane Shear Modulus (G_{xz})

Figure 8.1-13 shows the normalized in-plane Poisson's ratios when subjected to an in-plane tensile load. Figure 8.1-14 shows the normalized in-plane Poisson's ratios when subjected to an in-plane compressive load. The results in Figure 8.1-13 and 8.1-14 do not show direct relationships between temperature and the in-plane Poisson's ratio results for all material compositions.

The in-plane Poisson's ratio results at 140°F and -40°F are usually within 20% that at ambient temperatures. For four materials, under tension load and at a temperature of 140°F, the Poisson's ratio increases by more than 20%. The in-plane Poisson's ratio for Material 2-FY09 is significantly higher at a temperature of 140°F. This conclusion can be drawn under tensile loads and under compressive loads as evident from Figures 8.1-13 and 8.1-14, respectively. However, this trend is not consistent for other materials with Rencast 6405 and S2-glass.

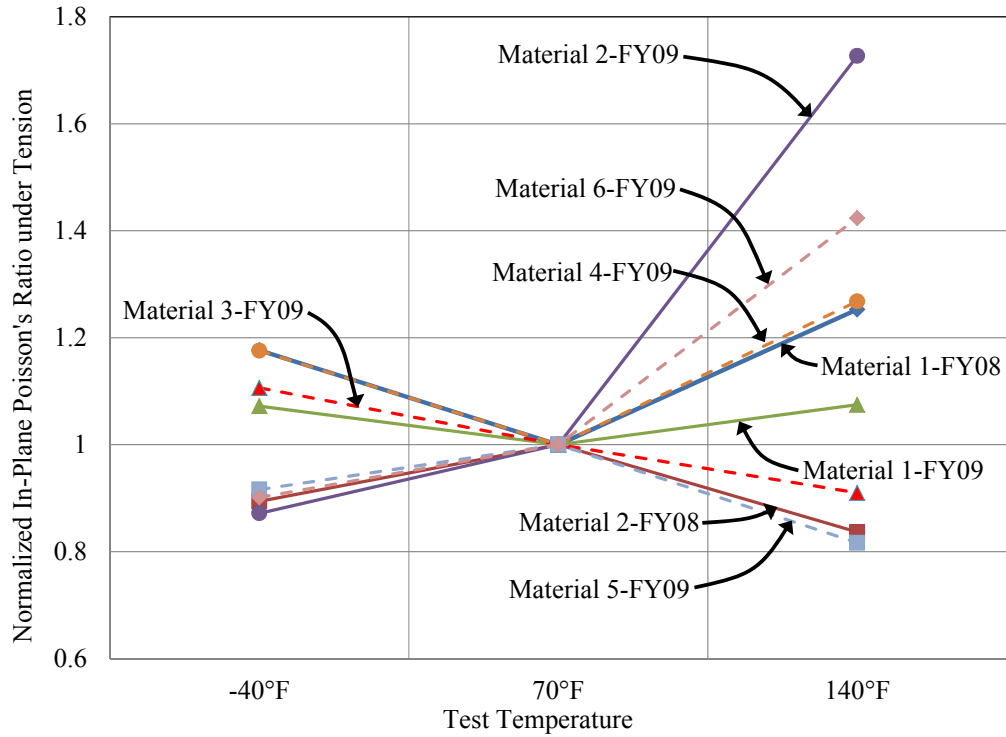


Figure 8.1-13: Effects of Temperature on In-Plane Poisson's Ratio under Tension (v_{xy})

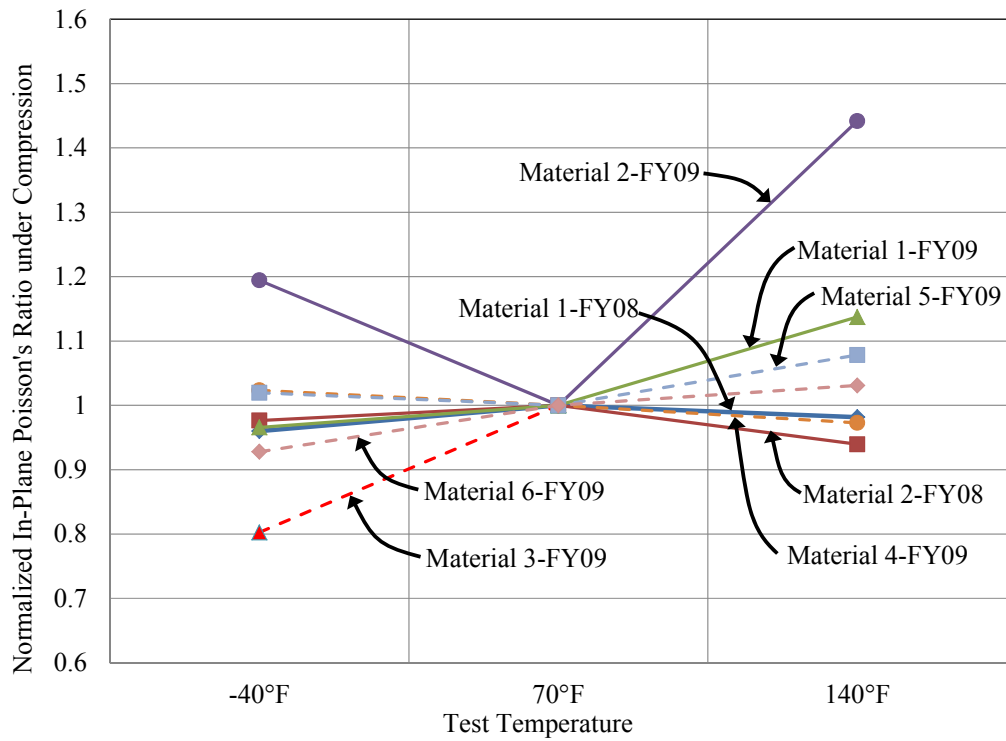


Figure 8.1-14: Effects of Temperature on In-Plane Poisson's Ratio under Comp. (v_{Cxy})

Figure 8.1-15 shows the normalized out-of-plane Poisson's ratio results when subjected to a tensile load. The results provided in Figure 8.1-15 show no trends in the influence of temperature on the out-of-plane Poisson's ratio results. The results at 140°F and -40°F are usually within 59% to 131% of that at ambient temperatures. However, and as mentioned in Section 5.7, uncharacteristic results were obtained for Material 2-FY08 at a test temperature of 140°F. The resulting Poisson's ratio was measured as negative. The results appear to be random and significant discrepancies are found in the data.

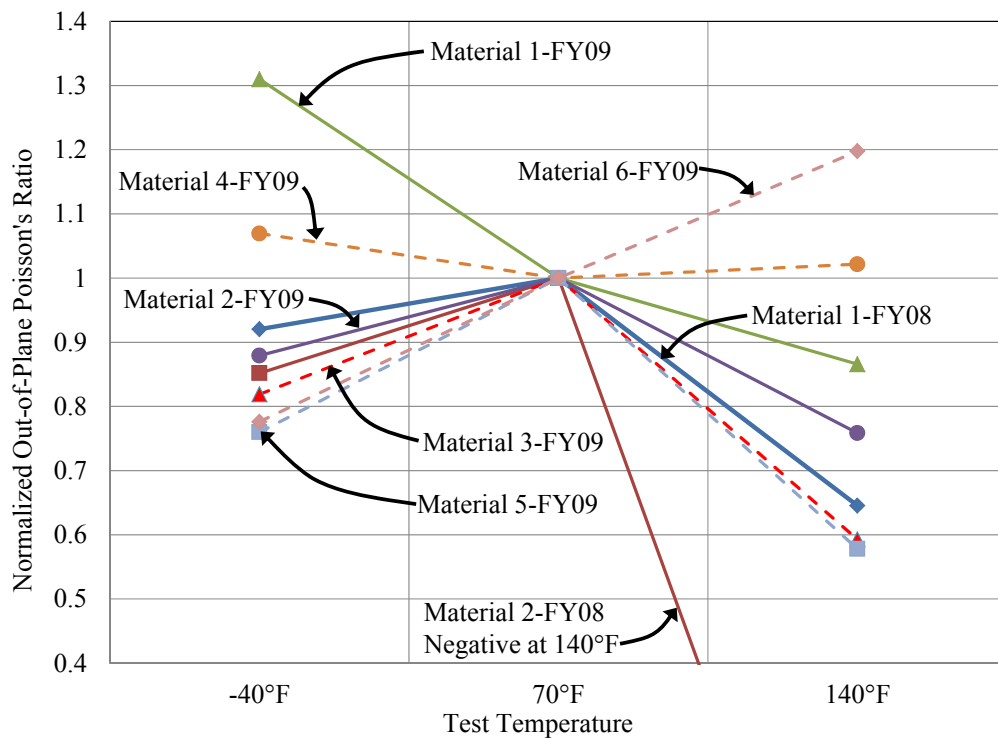


Figure 8.1-15: Effects of Temperature on Out-of-Plane Poisson's Ratio (v_{xz})

8.2 Thickness Effects

In the following subsections, the effects of nominal thickness on the material testing results will be analyzed. All composite materials that are composed of Huntsman Polyurethane Rencast 6405 (Rencast 6405) and S2-glass will be compared in Section 8.2.1. All materials with Applied Polymeric SC-15 Epoxy (SC-15 Epoxy) and S2-glass will be compared in Section 8.2.2. The graphs presented in the following sub-sections show normalized material testing results as a function of thickness. All results are normalized to the results for materials with 1.0 in. thickness.

With exception of the Poisson's ratio, the normalized results obtained at -40°F, 70°F, 140°F are averaged. One point on the graph represents the average obtained from all three temperatures. An example calculation is provided in Table 8.2-1. These normalized values are part of Figure 8.2-1.

Table 8.2-1: Example Calculation for Normalized Values in Thickness Comparison Figures

| Material | In-Plane Tension Strength (psi) | | | | Normalized Value |
|-----------------|---------------------------------|-------|-------|---------|-----------------------|
| | -40°F | 70°F | 140°F | Average | |
| Material 1-FY08 | 51720 | 48035 | 42203 | 47319 | = 47319/48731 = 0.971 |
| Material 4-FY09 | 53827 | 49131 | 43236 | 48731 | = 48731/48731 = 1.000 |
| Material 5-FY09 | 46837 | 45551 | 38130 | 43506 | = 43506/48731 = 0.893 |

8.2.1 Huntsman PolyUrethane Rencast 6405

The normalized ultimate strength results for Material 2-FY08, Material 1-FY09, and Material 2-FY09 are shown in Figure 8.2-1. Table 1.3-2 provides a description of the variables that are used to identify each line in the figure (e.g. S_{xy} represents in-plane shear strength). The normalized results include in-plane tension, in-plane compression, in-plane shear, out-of-plane tension, out-of-plane compression, and out-of-plane shear. The results are computed using average values from the three test temperatures.

In Figure 8.2-1, a 1.5 in. thickness represents the normalized results of Material 2-FY08, a 1.0 in. thickness represents the normalized results of Material 1-FY09, and a 0.75 in. thickness represents the normalized results of Material 2-FY09. As discussed in Section 8.2, results are normalized to the 1.0 in. thick material. Therefore, for all strength properties, the normalized value is always 1.0 for Material 1-FY09.

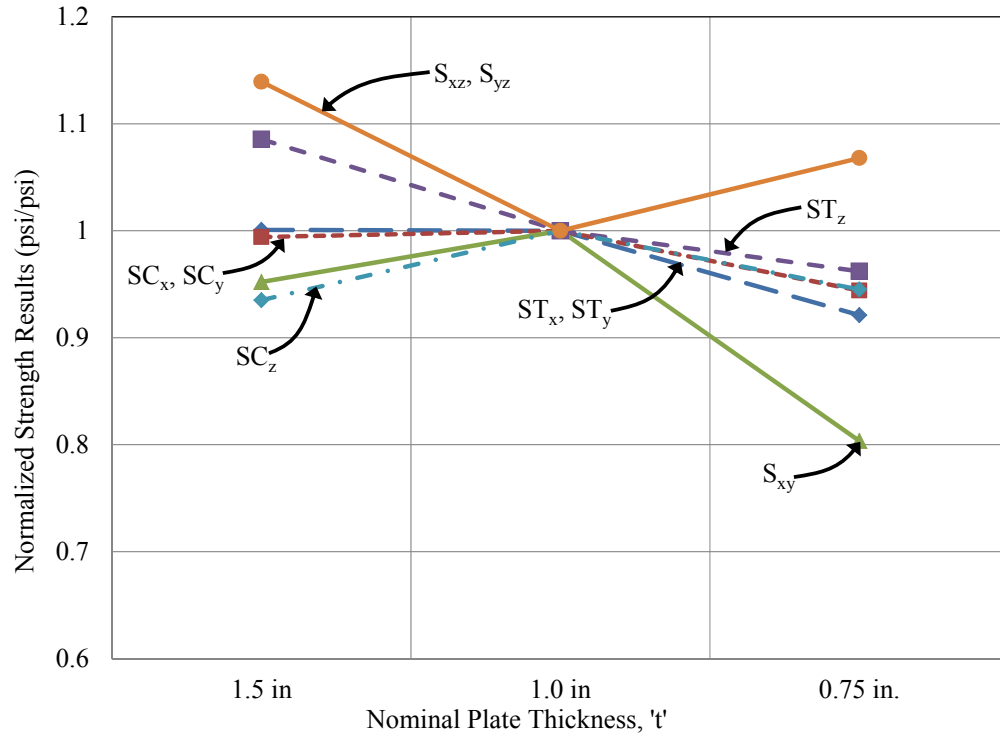


Figure 8.2-1: Effects of Composite Thickness on Material Strength (Rencast 6405 Material)

Figure 8.2-1 indicates that there is no direct influence of the material thickness on the strength results. For example, the in-plane shear strength (S_{xy}) increases from a material thickness of 0.75 in. to 1.0 in. and decreases from a material thickness of 1.0 in. to 1.5 in. Usually, strengths are lower for the material with a thickness of 0.75 in. in comparison to the material with a thickness of 1.0 in. The in-plane shear strength of Material 2-FY09 is 80% that of Material 1-FY09 which is the most significant comparison when analyzing the influence of thickness on material strengths.

The normalized stiffness results for Material 2-FY08, Material 1-FY09, and Material 1-FY09 are shown in Figure 8.2-2. The normalized relationships are similar to that for strength in Figure 8.2-1 and are calculated similar to that shown in Table 8.2-1. All stiffness results are normalized to the stiffness results obtained for the 1.0 in. material (Material 1-FY09). The normalized results include in-plane elastic modulus under tension loads, in-plane elastic modulus under compressive loads, in-plane shear modulus, out-of-plane elastic modulus under tension loads, out-of-plane elastic modulus under compressive loads, and out-of-plane shear modulus.

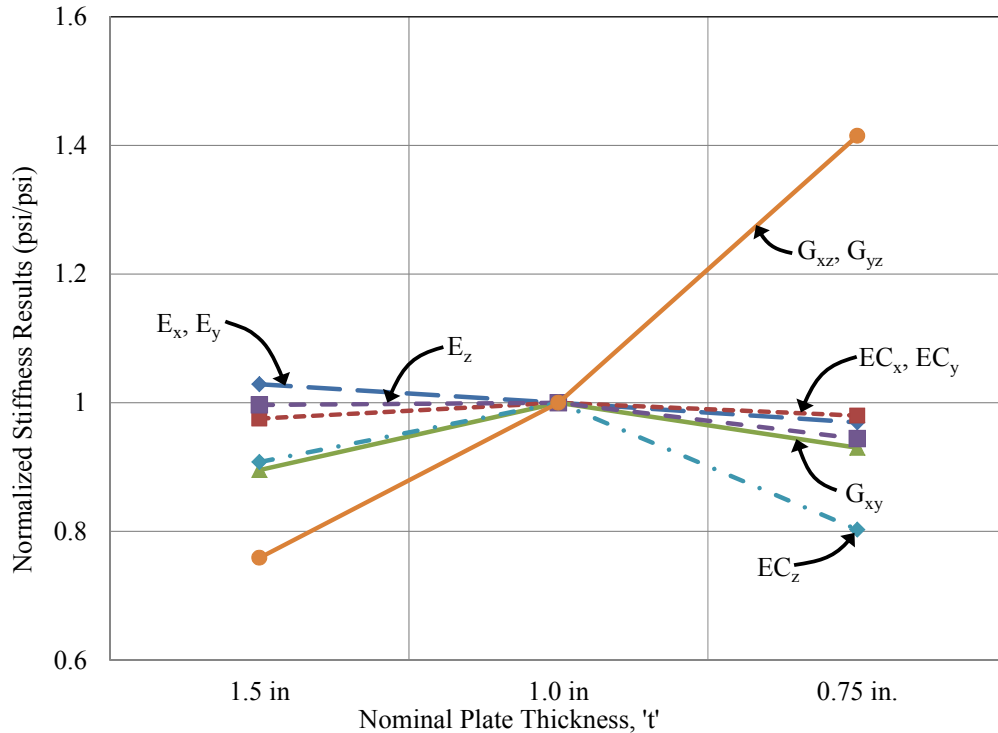


Figure 8.2-2: Effects of Composite Thickness on Material Stiffness (Rencast 6405 Material)

The results in Figure 8.2-2 indicate that material thickness does not have a significant influence on the stiffness results. With the exception of the out-of-plane shear modulus and the out-of-plane compressive elastic modulus, all results at material thickness of 1.5 in. or 0.75 in. are within 10% of that at 1.0 in.

The results indicate that the out-of-plane shear modulus increases with a decrease in material thickness. This result is uncharacteristic in comparison to the trends in the stiffness data and contradicts the results for materials with API SC-15 and S2-Glass as discussed in Section 8.2.2. The research team was not able to determine the reason the out-of-plane shear modulus varied significantly.

The normalized Poisson's ratios for Material 2-FY08, Material 1-FY09, and Material 2-FY09 are shown in Figure 8.2-3. The normalized results include the Poisson's ratio measured for the in-plane tension test, in-plane compression test, and out-of-plane tension test. All three temperatures are considered separately. The results provided in Figure 8.2-3 show no trends in the in-plane or out-of-plane Poisson's ratios when there is an increase or decrease in thickness. The Poisson's

ratio was generally lower at a material thickness of 1.5 in. However, the trends were not consistent when comparing the Poisson's ratio at 1.0 in. and 0.75 in.

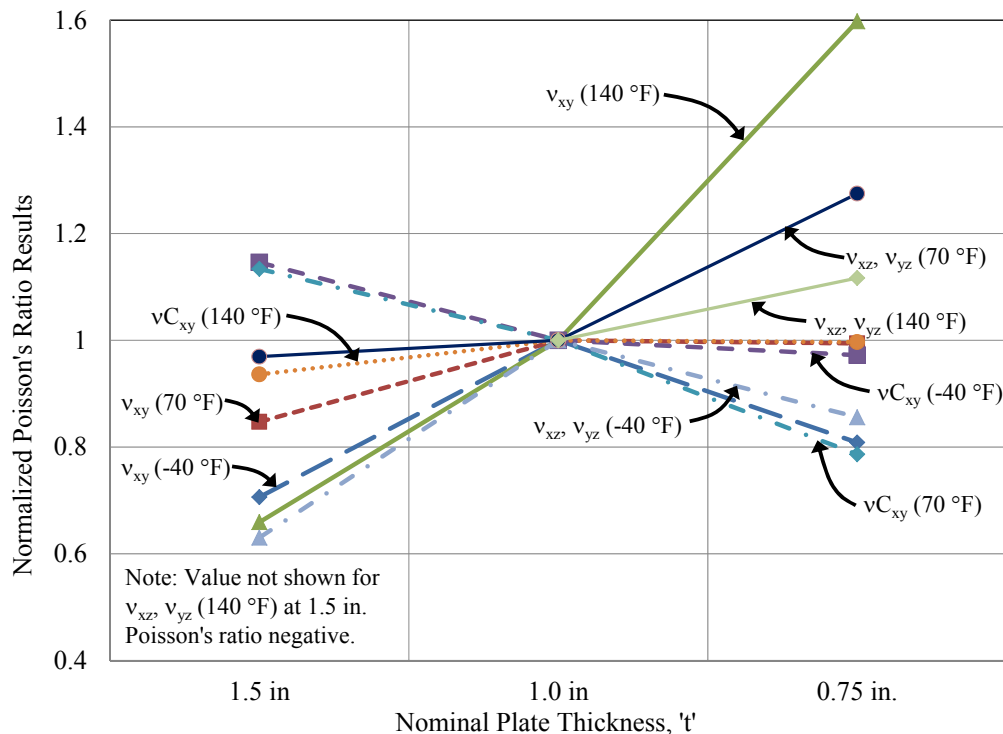


Figure 8.2-3: Effects of Composite Thickness on Poisson's Ratio (Rencast 6405 Material)

8.2.2 Applied Poleramic SC-15 Epoxy

The normalized ultimate strength results for Material 1-FY08, Material 4-FY09, and Material 5-FY09 are shown in Figure 8.2-4. The normalized results include in-plane tension, in-plane compression, in-plane shear, out-of-plane tension, out-of-plane compression, and out-of-plane shear. The results are computed using average values from the three test temperatures.

In Figure 8.2-4, a 1.5 in. thickness represents the normalized results of Material 1-FY08, a 1.0 in. thickness represents the normalized results of Material 4-FY09, and a 0.75 in. thickness represents the normalized results of Material 5-FY09. For all strength properties, the normalized value is always 1.0 for Material 4-FY09.

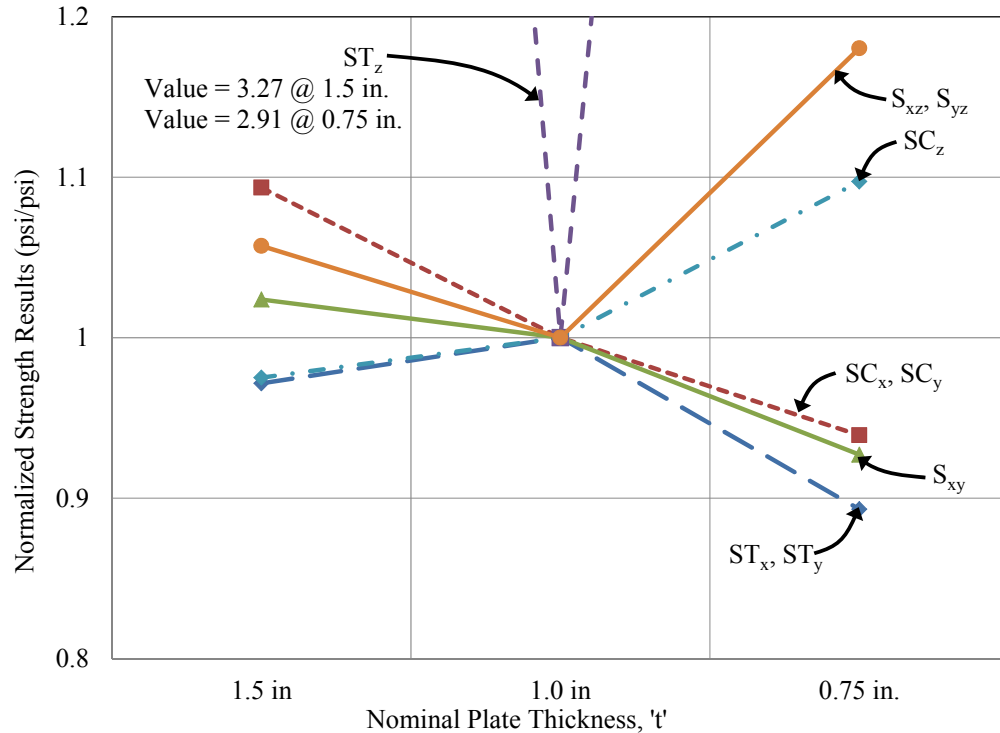


Figure 8.2-4: Effects of Composite Thickness of Material Strength (SC-15 Material)

Figure 8.2-4 indicates that the material thickness has a negligible and inconsistent influence on the strength results. The strength results for the materials with 1.5 in. and 0.75 in. thickness are always within 0.89 and 1.18 that of the material with 1.0 in. thickness. The only exception is for the out-of-plane tension strength which will be discussed in the following paragraph. The in-plane strengths decrease slightly when the material thickness decreases from 1.0 in. to 0.75 in. and the out-of-plane strengths increase slightly when the material thickness decreases from 1.0 in. to 0.75 in. However, these trends are inconsistent when the material thickness decreases from 1.5 in. to 1.0 in. The results indicate that the slight variations in material strengths are more dependent on the quality of the composite panel when fabricated and are not influenced by material thickness.

As shown in Figure 8.2-4, the out-of-plane tension strength at a material thickness of 1.0 in. is much lower than the out-of-plane tension strength at thickness of 0.75 in. and 1.5 in. Overall, the out-of-plane tension strength of Material 4-FY09 is low, lower than any material tested part of this research. After reviewing the comparison presented in Figure 8.2-4, the research team reviewed the test data and the failure surfaces of the specimens and compared them to the failure surfaces of

the Material 1-FY08 and Material 5-FY09 specimens. The research team was unable to determine why the strength was low but the low strength was consistent for all 15 specimens tested (5 at each temperature). The out-of-plane elastic modulus results are comparable to the results of the other two materials as shown in Figure 8.2-5 which is discussed in the preceding paragraph. The out-of-plane tension results for Material 1-FY08 and Material 5-FY09 are comparable. It is recommended that when composite materials are used in design and the design relies on out-of-plane properties, testing is performed for each batch to ensure the quality of the composite.

The normalized stiffness results for Material 1-FY08, Material 4-FY09, and Material 5-FY09 are shown in Figure 8.2-5. The normalized relationships are similar to that for strength and are calculated similar to that shown in Table 8.2-1. All stiffness results are normalized to the stiffness results obtained for the 1.0 in. material (Material 4-FY09). The normalized results include in-plane elastic modulus under tensile loads, in-plane elastic modulus under compressive loads, in-plane shear modulus, out-of-plane elastic modulus under tensile loads, out-of-plane elastic modulus under compressive loads, and out-of-plane shear modulus.

The results indicate that material thickness does not have an influence on the stiffness results. The normalized results range from 0.79 to 0.98 with an exception for out-of-plane shear which will be discussed in the following paragraph. The stiffness results increase slightly when the material thickness decreases from 1.5 in. to 1.0 in. and decrease slightly when the material thickness decreases from 1.0 in. to 0.75 in. Therefore, there is no direct relationship between material thickness and stiffness since the medium thickness has the highest results. The results appear to be more dependent on the quality of the material at fabrication.

The out-of-plane shear modulus results for Material 5-FY09 are uncharacteristically low. The research team was not able to determine why the values were low in comparison to Material 1-FY08 and Material 4-FY09. The low values are consistent for all 15 specimen tested (5 at each temperature).

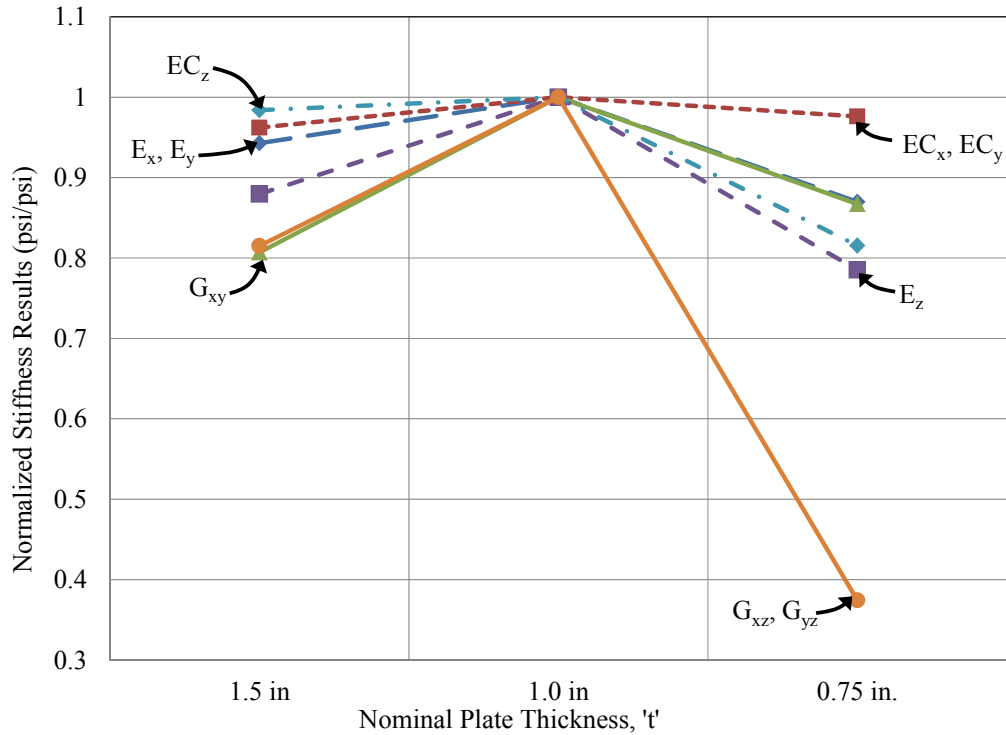


Figure 8.2-5: Effects of Composite Thickness of Material Stiffness (SC-15 Material)

The normalized Poisson's ratios for Material 1-FY08, Material 4-FY09, and Material 5-FY09 are shown in Figure 8.2-6. The normalized results include the Poisson's ratios when subjected to in-plane tension, in-plane compression, and out-of-plane tension. The results provided in Figure 8.2-6 show no trends in the in-plane or out-of-plane Poisson's ratios when there is an increase or decrease in thickness. The resulting Poisson's ratios appear random. However, all results at a material thickness of 1.5 in. and 0.75 in. are within 65%-130% of the values obtained at a material thickness of 1.0 in. Therefore, there is less variation in comparison to the materials with Huntsman Rencast 6405 and S2-glass.

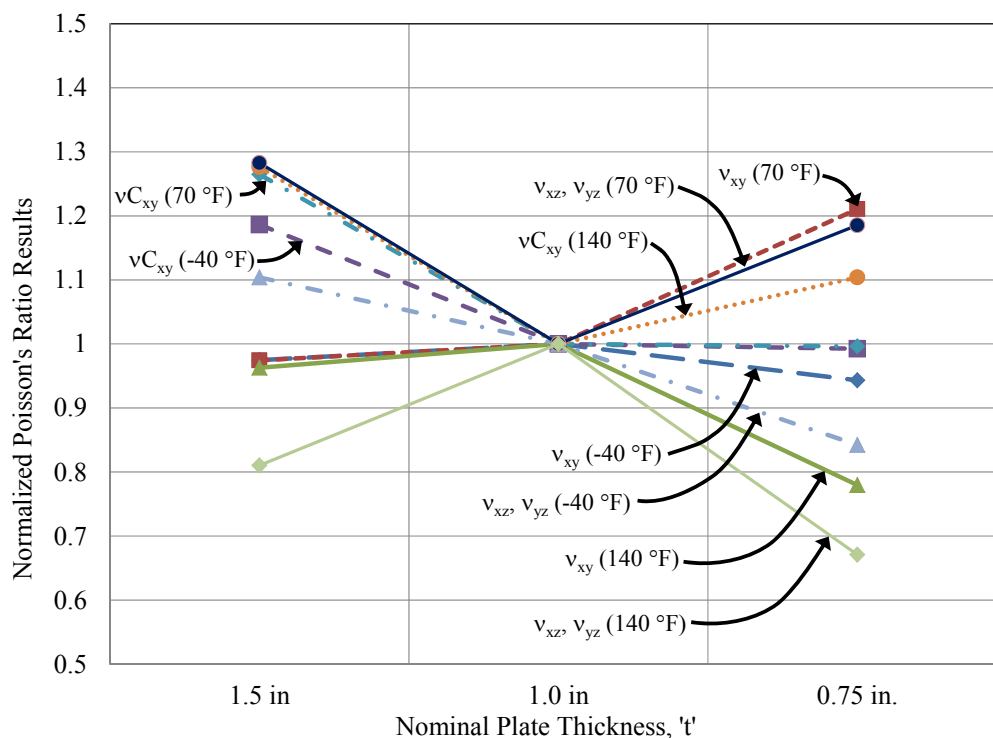


Figure 8.2-6: Influence of Thickness on Poisson's Ratio, Norm. Results (SC-15 Material)

8.3 Material Comparison

This section compares the different material compositions that are included as part of this research. In order to eliminate all other variables part of this research, the comparisons only include materials that are 0.75 in. thick. All four material compositions part of this research include a material with a thickness equal to 0.75 in. The results of Material 5-FY09, Material 2-FY09, Material 3-FY09, and Material 6-FY09 are provided for comparisons. These materials correspond to Applied Poleramic (API) SC-15 Epoxy with S2-glass fibers (API SC-15, S2-GLASS), Huntsman PU Rencast 6405 with S2-glass fibers (RENCAST 6405, S2-GLASS), Applied Polermeric (API) SC-15 Epoxy with S2-glass and aramid fibers (3D HYBRID PANELS), and Huntsman PU Rencast 6405 with ductile hybrid fabric (RENCAST 6405, DHF), respectively.

All results presented in this section are normalized to the results obtained for the composite with Applied Poleramic (API) SC-15 Epoxy and S2-glass fibers (Material 5-FY09). Two temperatures were chosen for this study; 70°F and 140°F. The results presented in Section 8.1 indicate that the strength and stiffness properties of the composite materials increase at a

temperature of -40°F and decrease at a temperature of 140°F. Therefore, the comparisons at high temperatures are more valuable than the comparisons at low temperatures.

Figure 8.3-1 compares the in-plane strength properties of the four different material compositions. The results indicate that materials with SC-15 epoxy are stronger than materials with Huntsman Rencast 6405. Material 3-FY09 has the highest resulting in-plane tension strength and in-plane compressive strength. The in-plane tensile strength of Material 3-FY09 at a temperature of 140°F is approximately two times higher than that of any other material. The material with SC-15 epoxy and S2-glass fibers (Material 5-FY09) resulted in the highest in-plane shear strength, both at ambient and elevated temperatures.

Figure 8.3-1 reinforces the results discussed in Section 8.1 that materials with Huntsman Rencast 6405 are influenced more significantly by temperature than materials with SC-15 epoxy. For example, the compressive strength of Material 2-FY09 is 82% that of Material 5-FY09 at a temperature of 70°F and 40% that of Material 5-FY09 at a temperature of 140°F.

Figure 8.3-1 indicates that the material with ductile hybrid fabric (Material 6-FY09) results in slightly higher strengths than the equivalent material with S2-glass (Material 2-FY09). This conclusion can be drawn for all properties shown in Figure 8.3-1 except for the in-plane shear strength at a temperature of 70°F.

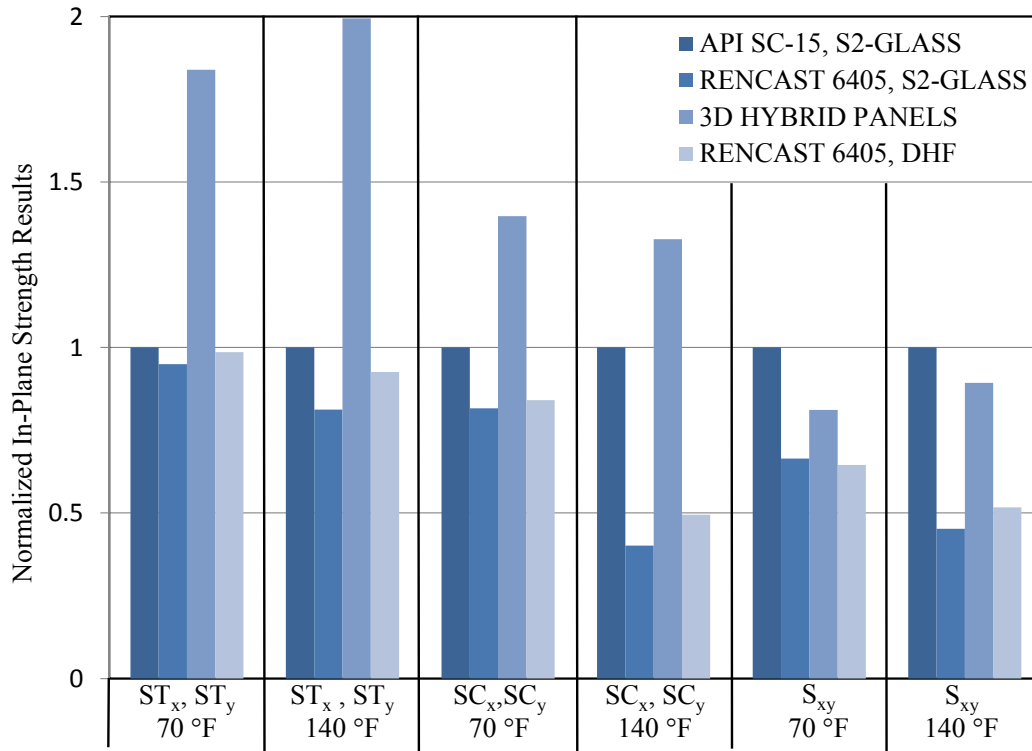


Figure 8.3-1: Comparison of In-Plane Strength Results for Different Materials

Figure 8.3-2 compares the out-of-plane strength properties of the four different material compositions. The out-of-plane tensile strength of Material 3-FY09 is significantly higher than that of all other materials. This result is attributed to the arrangement of aramid fibers along the z-axis. The out-of-plane tensile strength of Material 3-FY09 is 77% higher than that for Material 5-FY09. However, Material 3-FY09 has lower out-of-plane compressive strength and comparable out-of-plane shear strength. Therefore, the inclusion of aramid fibers along the z-axis only significantly enhances the tensile strength.

Figure 8.3-2 indicates that materials with Rencast 6405 have lower out-of-plane strengths than the materials with SC-15 epoxy. This comparison is consistent for out-of-plane tension, out-of-plane compression, and out-of-plane shear. In addition, the materials with Rencast 6405 are influenced more significantly by temperature than materials with SC-15 epoxy. For example, the out-of-plane tensile strength of Material 2-FY09 is 84% that of Material 5-FY09 at a temperature of 70°F and 47% that of Material 5-FY09 at a temperature of 140°F. The results for Material 2-FY09 and Material 6-FY09 are comparable.

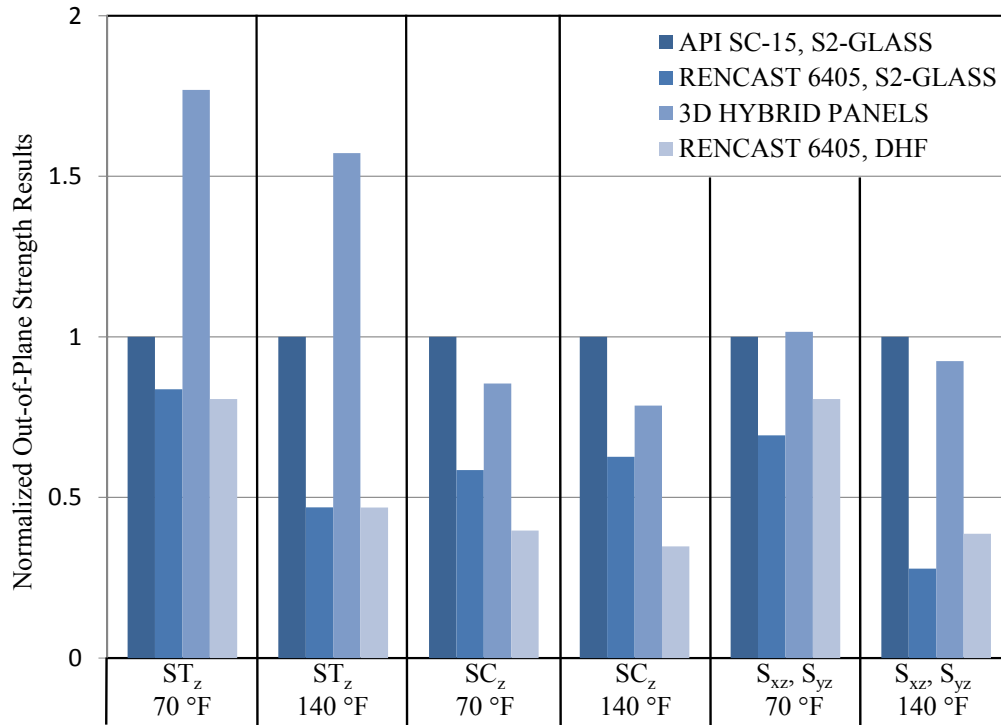


Figure 8.3-2: Comparison of Out-of-Plane Strength Properties for Different Materials

Figure 8.3-3 compares the in-plane stiffness properties of the four different material compositions. The results indicate that Material 6-FY09 with ductile hybrid fabric has a significantly higher in-plane tension elastic modulus than the other materials tested. In addition, this material has the highest in-plane compressive elastic modulus and the highest in-plane shear modulus. This result is attributed to the ultra-high modulus carbon fibers, part of ductile hybrid fabric.

Material 3-FY09 has the second highest in-plane elastic modulus properties. However, this material exhibited a low shear modulus in comparison to other materials. This material was subjected to extremely high shear strains prior to failure and did not exhibit elastic behavior over a significant portion of the stress-strain curve when compared to the elastic behavior of other materials.

Figure 8.3-3 indicates that the in-plane stiffness of materials with Huntsman Rencast 6405 is influenced slightly more by temperature than materials with SC-15 epoxy. For example, the in-plane shear modulus of Material 2-FY09 is 88% that of Material 5-FY09 at a temperature of 70°F

and 69% that of Material 5-FY09 at a temperature of 140°F. Overall, the material with SC-15 epoxy and S2-glass fibers is stiffer than the material with Huntsman Rencast 6405 and S2-glass fibers.

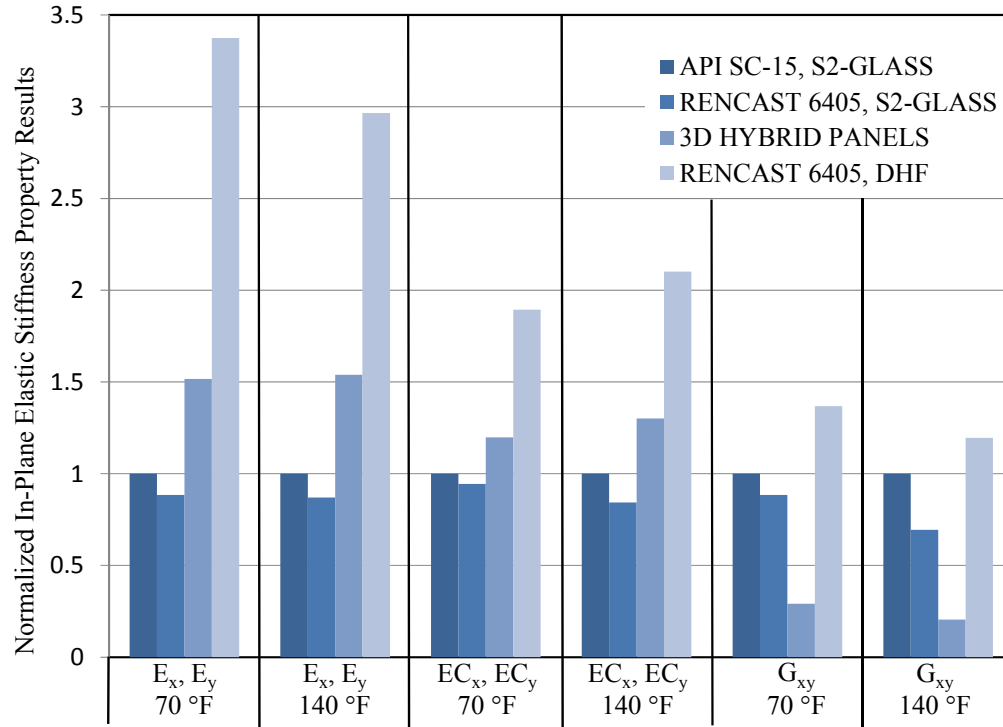


Figure 8.3-3: Comparison of In-Plane Stiffness Properties for Different Materials

Figure 8.3-4 compares the out-of-plane stiffness properties of the four different material compositions. The results indicate that Material 3-FY09 has the highest out-of-plane tension elastic modulus when tested at ambient temperatures. The tension elastic modulus is 28% higher than that of Material 5-FY09 which is composed of S2-glass and API SC-15 epoxy. However, when tested at a temperature of 140°F, the out-of-plane tension elastic modulus of Material 3-FY09 is slightly lower. The out-of-plane compressive elastic modulus and out-of-plane shear modulus of Material 3-FY09 are lower than that of Material 5-FY09. The differences are more significant when tested at a test temperature of 140°F.

Figure 8.3-4 indicates that the out-of-plane stiffness properties of materials with Rencast 6405 are usually lower than those with SC-15 epoxy. The only exception is the out-of-plane shear modulus at a test temperature of 70°F. For this scenario, the out-of-plane shear modulus of

Material 2-FY09 was 34% higher than that of Material 5-FY09. The out-of-plane shear modulus and the out-of-plane tension elastic modulus of materials with Rencast 6405 are influenced more significantly by temperature than materials with SC-15 epoxy. For example, the out-of-plane shear modulus of Material 2-FY09 is 134% that of Material 5-FY09 at a temperature of 70°F and 14% that of Material 5-FY09 at a temperature of 140°F. These comparisons further indicate that materials with Huntsman Rencast 6405 have unfavorable material properties when elevated temperatures are anticipated.

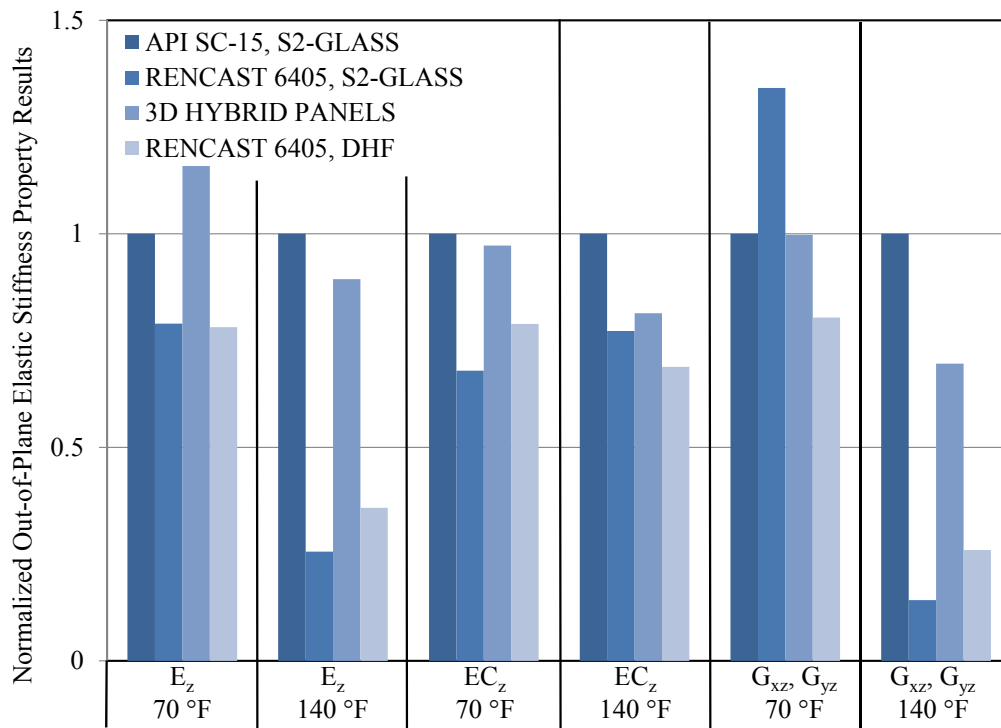


Figure 8.3-4: Comparison of Out-of-Plane Stiffness Properties for Different Materials

8.4 Tension Properties vs. Compression Properties

This section compares the results obtained when materials are subjected to tension vs. the results obtained when materials are subjected to compression. The results presented in the graphs which are included in this section are not normalized. The tension and compression testing results are compared using bar charts and are shown directly next to each other. Two temperatures were chosen for this study; 70°F and 140°F. The temperature of -40°F was not chosen since low temperatures generally do not have adverse effects on the strength and stiffness results. All eight

materials are considered. However, the average results for the three materials with Huntsman PolyUrethane Rencast 6405 and S2-glass are used for the comparisons and average results for the three materials with Applied Poleramic SC-15 Epoxy and S2-glass are used for the comparisons.

Figure 8.4-1 shows a comparison between the in-plane tensile strength and the in-plane compressive strength results for all materials at the two different temperatures. The results clearly indicate that the composite materials have higher in-plane tension strengths than in-plane compressive strengths where fibers contribute more to resisting the axial load. The tensile and compressive strength results are similar for the materials with SC-15 epoxy and S2-glass fibers. Both materials with Huntsman Rencast 6405 are much weaker in compression especially when subjected to elevated temperatures. This result is attributed to the epoxy having a higher contribution to the resistance of compression as opposed to tension.

Material 3-FY09 (3D Hybrid Panel) is significantly weaker in compression as opposed to tension. This material is significantly stronger in tension than all other materials tested. It is also the strongest material in compression at both ambient and elevated temperatures.

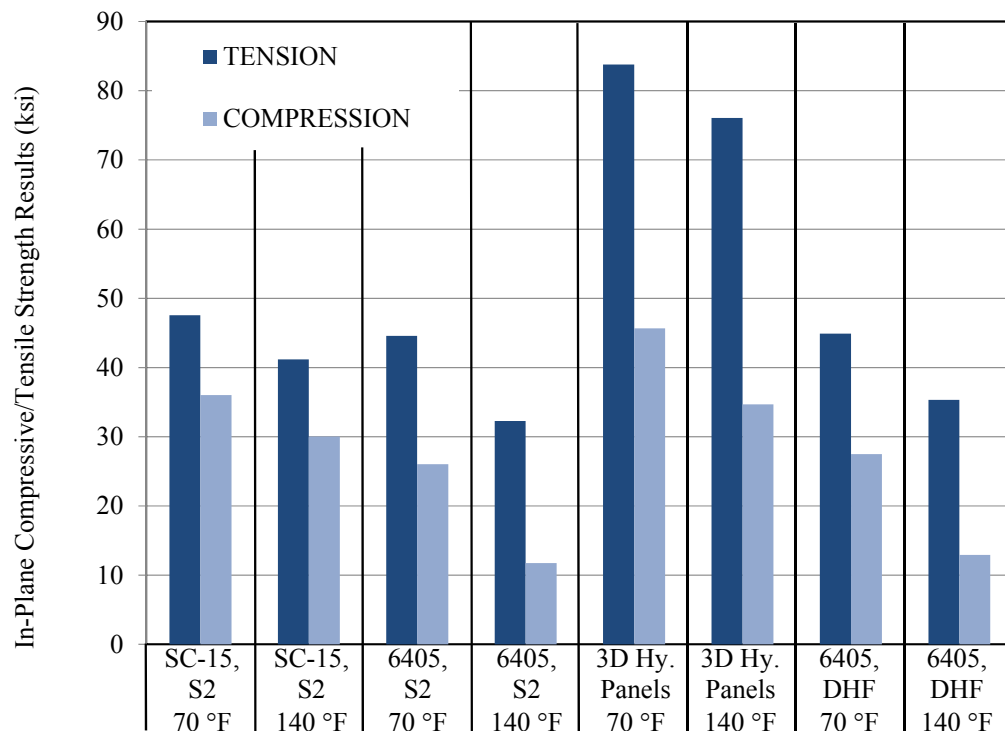


Figure 8.4-1: Comparison of In-Plane Tensile and In-Plane Compressive Strengths

Figure 8.4-2 shows a comparison between the out-of-plane tensile strength and the out-of-plane compressive strength results for all materials at the two different temperatures. The out-of-plane tensile strength which is primarily governed by the strength of the resin is not comparable to the out-of-plane compressive strength. The out-of-plane compressive strength is as much as 25X higher than the out-of-plane tensile strength.

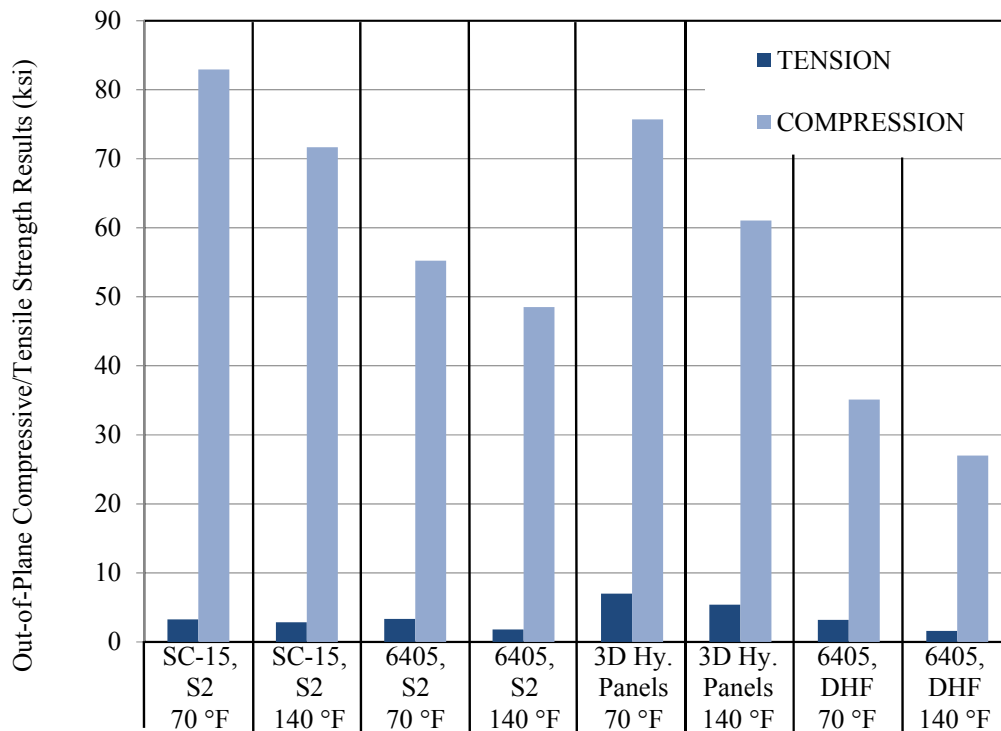


Figure 8.4-2: Comparison of Out-of-Plane Tensile and Out-of-Plane Compressive Strengths

Figure 8.4-3 shows a comparison between the in-plane tensile elastic modulus and the in-plane compressive elastic modulus for all materials at the two different temperatures. The results typically indicate that the in-plane compressive modulus is higher than the in-plane tension modulus. These relative comparisons at both temperatures are fairly consistent for three of the four materials tested. However, the in-plane tension modulus of Material 6-FY09 is higher than the in-plane compressive modulus. This result is attributed to the ultra-high modulus carbon fibers, part of the ductile hybrid fabric.

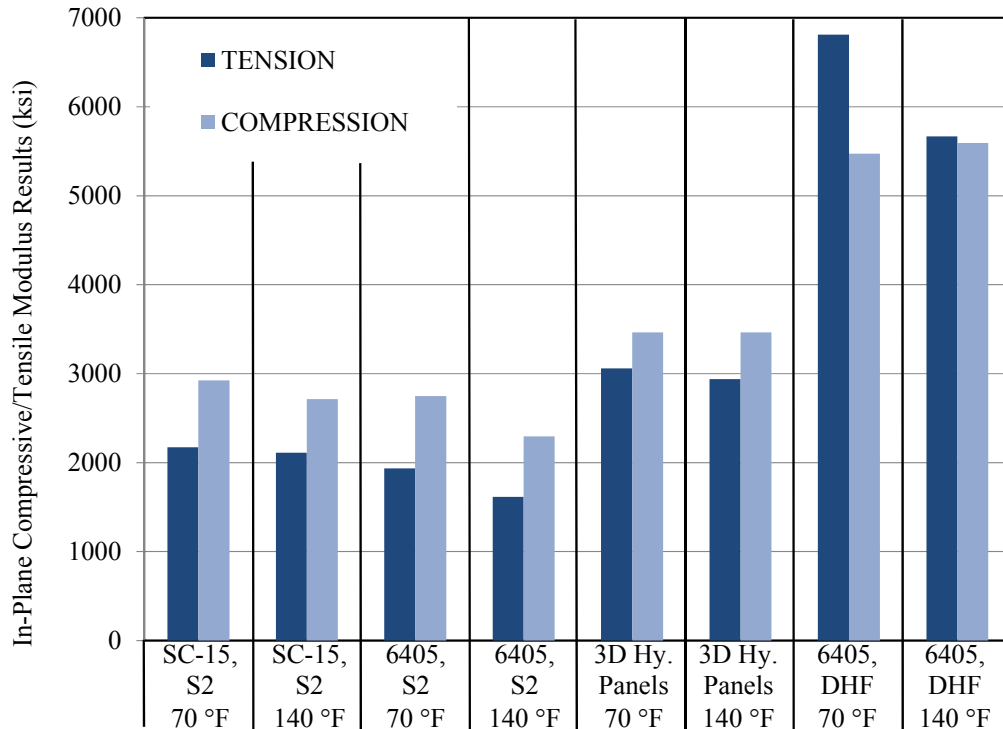


Figure 8.4-3: Comparison of In-Plane Tensile and In-Plane Compressive Elastic Modulus

Figure 8.4-4 shows a comparison between the out-of-plane tensile elastic modulus and the out-of-plane compressive elastic modulus results for all materials at the two different temperatures. The results in Figure 8.4-4 show no direct influence of the direction of load on the elastic modulus results. In some cases, the out-of-plane tensile elastic modulus is higher than the out-of-plane compressive elastic modulus. In other cases, the out-of-plane compressive elastic modulus is higher. Usually, the compressive and tensile results are comparable with some exceptions. The out-of-plane tensile modulus of Material 3-FY09 is significantly higher than the out-of-plane compressive modulus which is likely due to the inclusion of aramid fibers that assist in resisting load when subjected to tension.

At a test temperature of 140°F, the out-of-plane tensile modulus of both materials with Rencast 6405 is significantly lower than the out-of-plane compressive modulus. The results are comparable for both materials at 70°F.

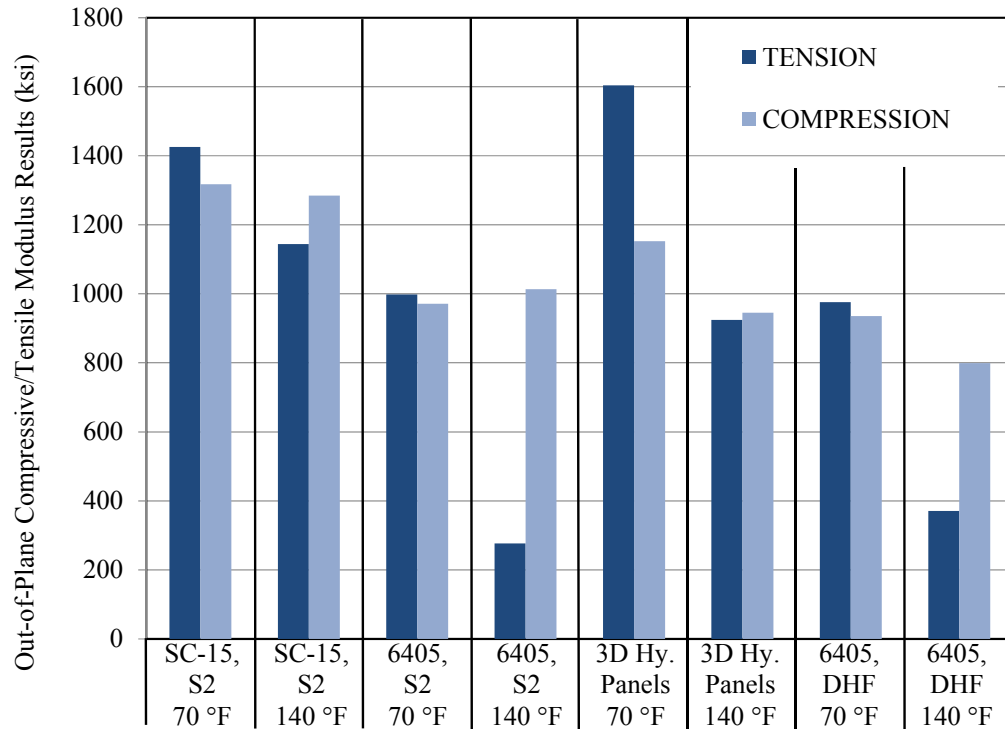


Figure 8.4-4: Comparison of Out-of-Plane Ten. and Out-of-Plane Comp. Elastic Modulus

8.5 Statistical Analysis of Results using Coefficient of Variation

This section investigates the statistical significance of the experimental results considering the standard deviations of each individual sample set (results from group of five specimens tested for each material, each test type, and each test temperature). All individual specimen results are considered in this study in lieu of the mean values of the five specimens tested. To simplify the comparisons of the different properties measured in this research, the coefficient of variance (*CV*) is computed for each result and shown on the figures presented in this section. This property is defined in Equation 1 where σ is equal to one standard deviation and μ is equal to the mean value:

$$CV = \frac{\sigma}{\mu} * 100\% \quad (1)$$

All means, standard deviations, and *CVs* are shown for all sample sets in Appendix J.

Figure 8.5-1 shows the *CVs* for each sample set of in-plane properties. All eight materials tested at each test temperature are included in Figure 8.5-1. For each property, the standard

deviation computed from the five specimens tested is divided by the mean and multiplied by 100%. The data in Figure 8.5-1 represents a large sample size and individual data points are difficult to identify. However, this graph assists in understanding which properties have high CV s and how temperature influences the results. In Figure 8.5-1, diamonds are used to represent CV s at a temperature of -40°F, squares are used to represent CV s at a temperature of 70°F, and triangles are used to represent CV s at a temperature of 140°F. For example, a square for the property ST_x represents one CV for one material and eight squares represent the results of all eight materials.

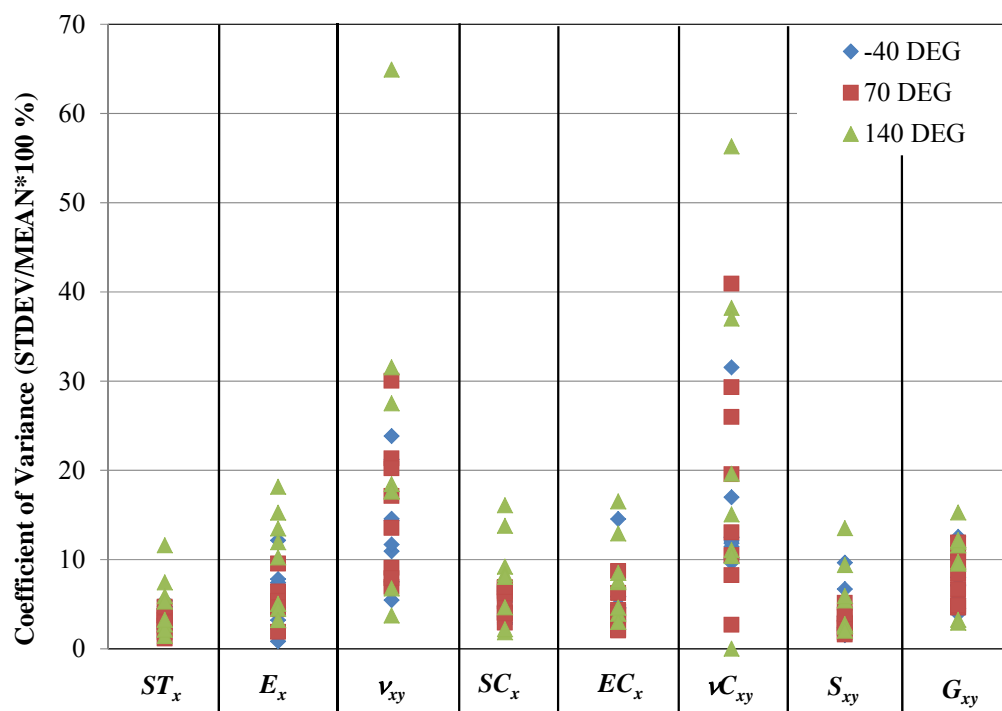


Figure 8.5-1: Coefficient of Variance for In-Plane Material Properties, All Materials

Figure 8.5-1 indicates that in-plane strength properties have low CV s and therefore, the in-plane strength results are statically significant. All values are 16% or less. Figure 8.5-1 also indicates that the stiffness properties have relatively low CV s. All results are below 20%. The results in Figure 8.5-1 indicate that more statistical variance exists in the in-plane strength and stiffness results when tests are performed at 140°F. Therefore, the results presented in Figure 8.5-1 in conjunction with the results presented in Section 8.1 indicate that the composite materials are weaker, less stiff, and the results are less reliable at elevated temperatures.

Figure 8.5-1 indicates that the in-plane Poisson's ratio results have high CVs . Higher CVs are found for material results tested at a test temperature of 140°F. The resulting Poisson's ratio results presented are less reliable than the strength and stiffness results.

Figure 8.5-2 shows the CVs for each sample set of out-of-plane properties. All eight materials tested at each test temperature are included in Figure 8.5-2. The development of Figure 8.5-2 is similar to the development of Figure 8.5-1.

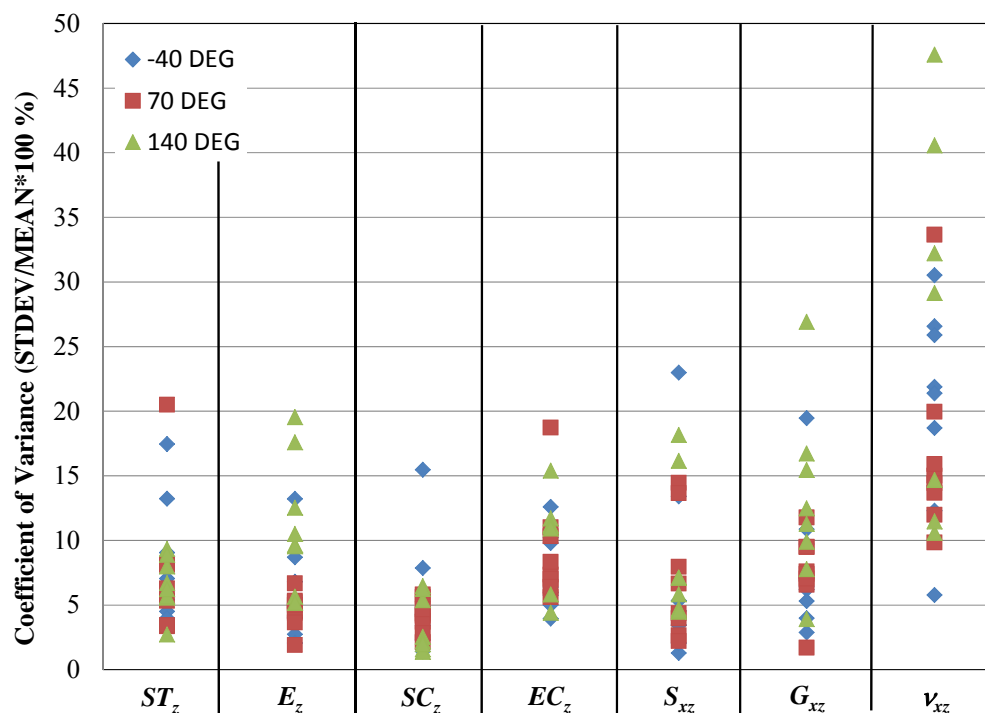


Figure 8.5-2: Coefficient of Variance for Out-of-Plane Material Properties, All Materials

Figure 8.5-2 indicates that the out-of-plane strength and stiffness properties have fairly low CVs . However, dissimilar from the in-plane strength and stiffness properties, there are outliers in the data. All values are 27% or less with most values under 20%. Testing at elevated temperatures is not as significant for the resulting out-of-plane CVs in comparison to the results for the in-plane CVs . However, the CVs are usually higher at test temperature of 140°F.

The results from the out-of-plane tension tests and out-of-plane shear tests appear less reliable than the results from the out-of-plane compression tests. With the exception of one test, all CVs are 7% or less for all out-of-plane compressive strength results (SC_z).

Figure 8.5-2 indicates that the out-of-plane Poisson's ratio results have higher *CVs* than the out-of-plane strength and stiffness properties. The values are as high as 48%.

The resulting *CVs* are further analyzed using bar charts in Figures 8.5-3 to 8.5-7. All three temperatures are used for this study. In addition, all eight materials are considered. However, the average results for the three materials with Huntsman PU Rencast 6405 and S2-glass are used for the comparisons and average results for the three materials with Applied Poleramic SC-15 Epoxy with S2-glass are used for the comparisons.

Figure 8.5-3 shows the resulting *CVs* that represent the in-plane strength properties of the four different material compositions. The results indicate that the material testing results of Material 6-FY09 (DHF material) are less reliable than the material testing results of other materials as evident by the *CVs*. The *CV* for in-plane tension is nearly 12% for this material at a temperature of 140°F. In general, the results for materials with SC-15 epoxy are more reliable than the results for materials with Huntsman Rencast 6405. This comparison is more significant at a temperature of 140°F. From the general trends in the data, the in-plane compressive strength is usually less reliable than the in-plane tensile strength and the in-plane shear strength. However, all *CV* results are less than 12% which is fairly low.

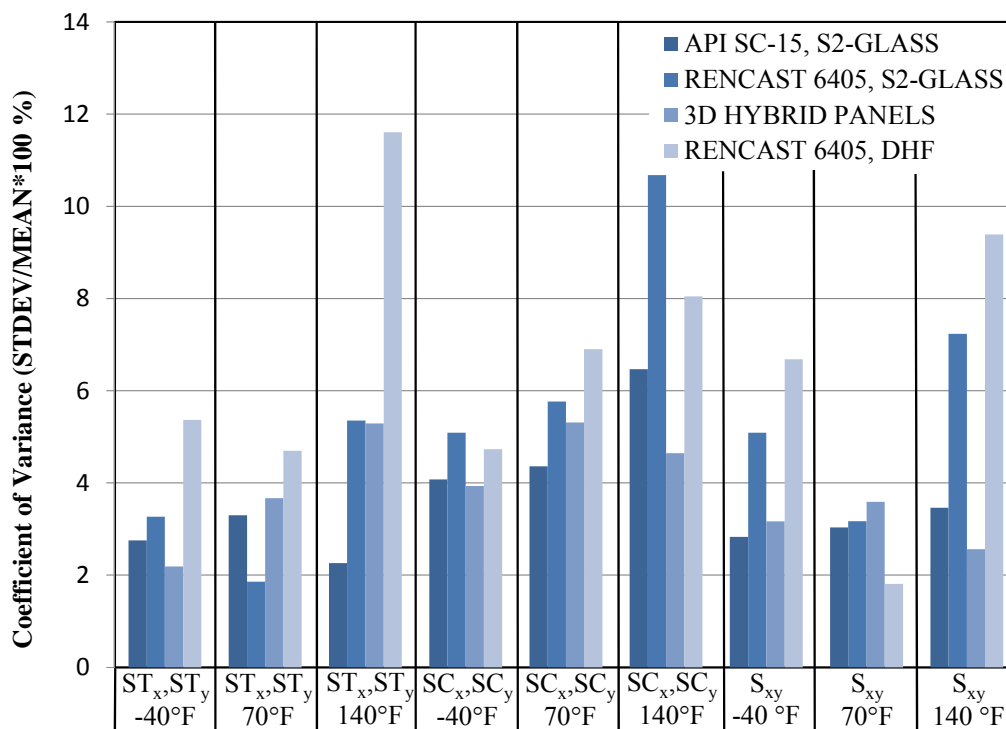


Figure 8.5-3: Coefficient of Variance for In-Plane Strength Properties

Figure 8.5-4 shows the resulting *CVs* that represent the out-of-plane strength properties of the four different material compositions. The results indicate that the out-of-plane compressive strength results are more reliable than the out-of-plane shear strength results and the out-of-plane tensile strength results. With the exception of one result presented in Figure 8.5-4, all *CVs* for out-of-plane compressive strength are less than 5%.

The resulting *CVs* are fairly low for the out-of-plane tensile strengths. All results presented in Figure 8.5-4 are less than 13%. For all three test temperatures, the *CVs* are highest for materials with API SC-15 epoxy and S2-glass and the lowest for Material 3-FY09. This result is anticipated because aramid fibers should be more reliable than the materials with only epoxy resisting the load.

Figure 8.5-4 indicates that the out-of-plane shear strength results are less statistically significant particularly for Material 3-FY09 and Material 6-FY09. The results for Material 3-FY09 at a test temperature of -40°F are as high as 23%. The results for both materials at a test temperature of 140°F are higher than 15%.

The out-of-plane shear test is conducted with a specimen with a fairly small cross-sectional area and the load required to initiate failure is small. Therefore, the test may be more sensitive than other tests performed and imperfections between laminas may have a more significantly influence on the results.

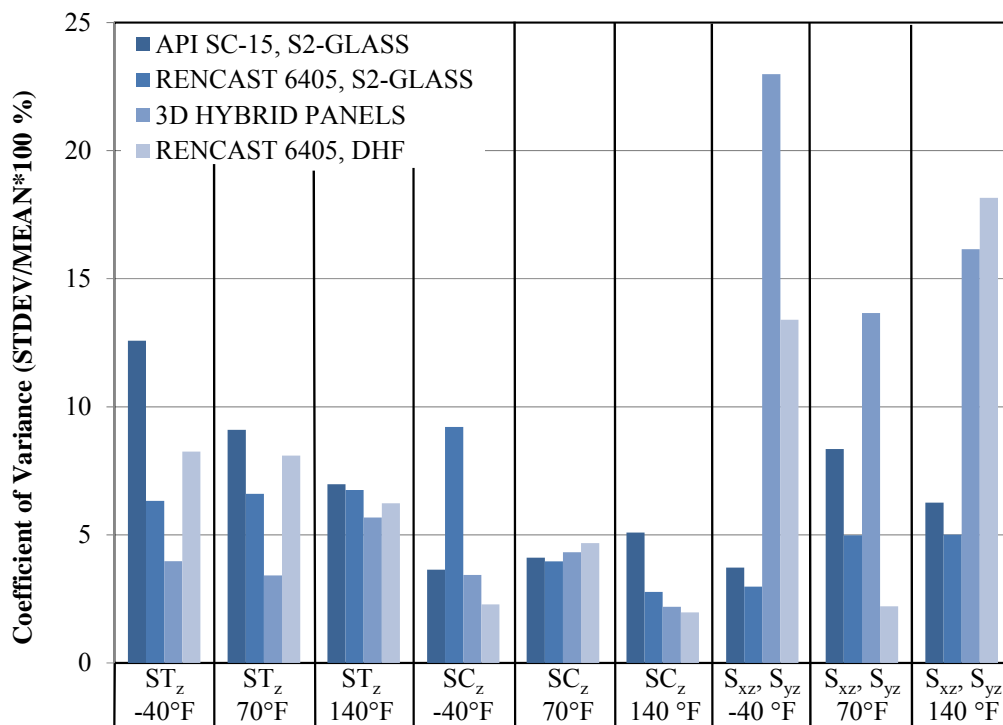


Figure 8.5-4: Coefficient of Variance for Out-of-Plane Strength Properties

Figure 8.5-5 shows the resulting CV s that represent the in-plane stiffness properties of the four different material compositions. All CV results for the in-plane stiffness properties are less than 17%. The results indicate that the material testing results of Material 6-FY09 (DHF material) are usually less reliable than the material testing results of other materials. The in-plane stiffness results of materials will Huntsman Rencast 6405 and S2-glass fibers are less reliable at a temperature of 140°F.

The results of materials with SC-15 epoxy and S2-glass fibers are often the most reliable. From the general trends in the data, the in-plane shear modulus is usually less reliable than the in-plane tensile elastic modulus and the in-plane compressive elastic modulus.

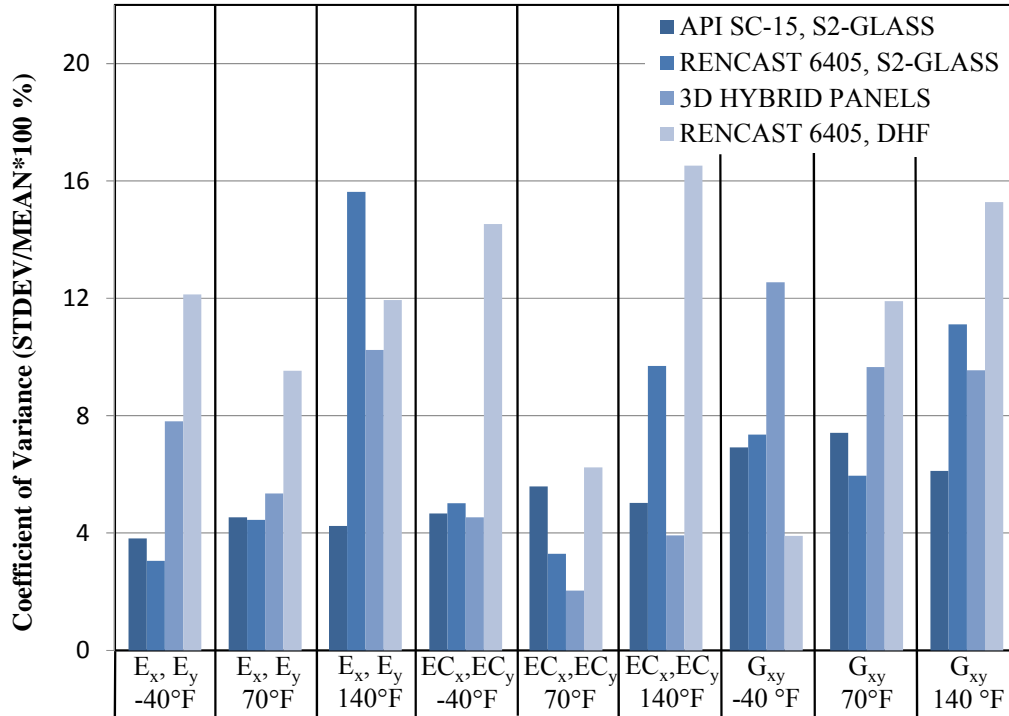


Figure 8.5-5: Coefficient of Variance for In-Plane Stiffness Properties

Figure 8.5-6 shows the resulting *CVs* that represent the out-of-plane stiffness properties of the four different material compositions. The results indicate that the out-of-plane stiffness results are less statistically significant at a test temperature of 140°F. Figure 8.5-6 does not reveal any other notable trends. All results are less than 15% with the exception of the out-of-plane tension modulus and the out-of-plane shear modulus for Material 6-FY09 at a test temperature of 140°F.

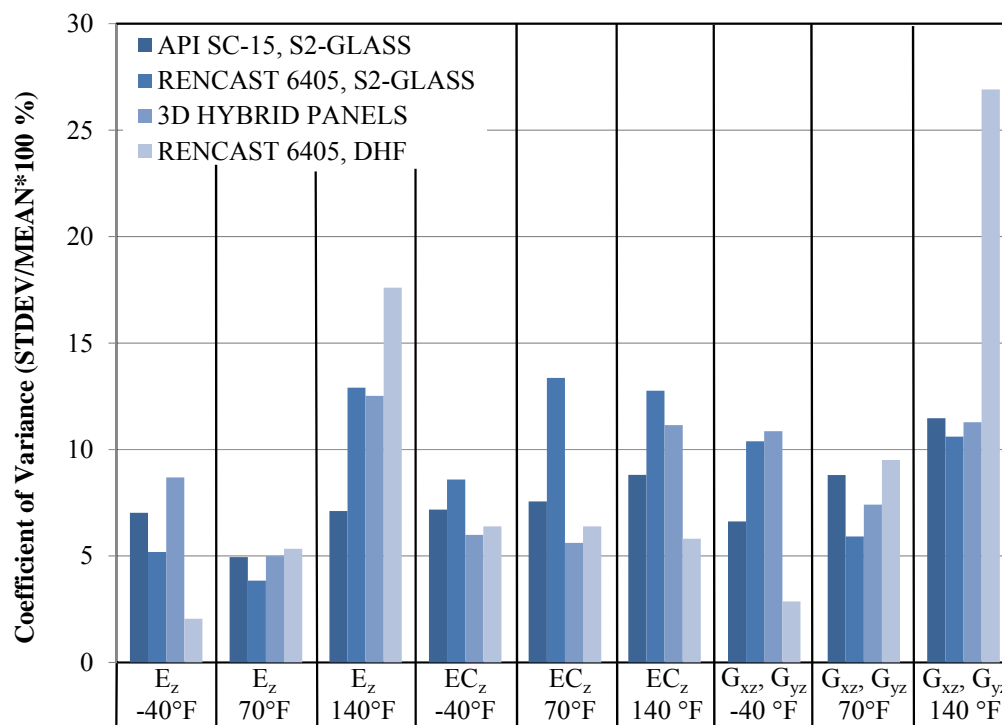


Figure 8.5-6: Coefficient of Variance for Out-of-Plane Stiffness Properties

Figure 8.5-7 shows the resulting CV s that represent the Poisson's ratio results of the four different material compositions. Note the following:

- The out-of-plane Poisson's ratio of Material 2-FY08 at a test temperature of 140°F was negative and was not considered in the average CV s of materials with Rencast 6405 and S2-glass.
- The in-plane compressive Poisson's ratio for Material 3-FY09 at a test temperature of 140°F could not be interpreted from the data. Therefore, the CV is shown as zero.

The Poisson's ratio results have higher CV s when compared to the strength and stiffness results. The results in Figure 8.5-7 indicate that the out-of-plane Poisson's tests are sometimes more reliable than the in-plane Poisson's ratio results. However, when performing the out-of-plane Poisson's ratio test, the research team is focused on achieving a mean Poisson's ratio using a set of relatively consistent data. The in-plane tests focus on the in-plane strength and stiffness properties and not particularly on the Poisson's ratio.

The calculated CV s for the Poisson's ratio are often highest for Material 6-FY09 and sometimes highest for Material 3-FY09 and the materials with Rencast 6405 an S2-glass. The results of materials with SC-15 epoxy and S2-glass fibers are usually the most reliable. Overall, the Poisson's ratio both in-plane and out-of-plane is the most difficult property to accurately measure for composite materials. The property is dependent on the epoxy/resin composition within an individual specimen and the edge condition where the strain gauges are attached.

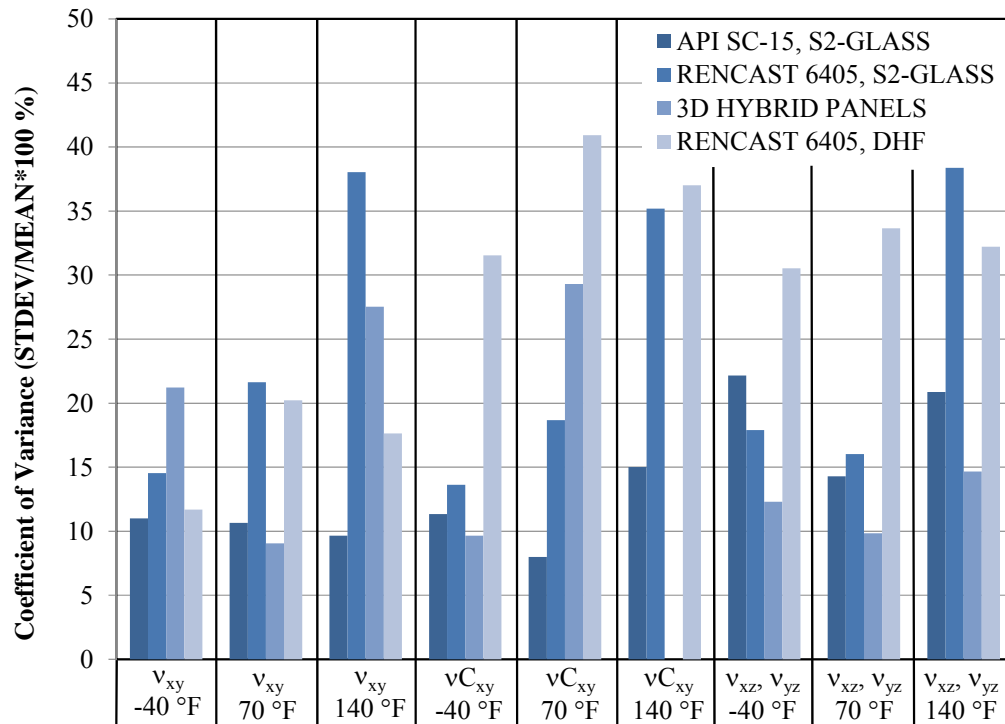


Figure 8.5-7: Coefficient of Variance for Poisson's Ratio Results

CHAPTER 9: CONCLUSIONS

This research was performed to determine test procedures for measuring the material properties of fiber-reinforced composite materials with respect to all three material axes. In addition, this research was performed to determine the material properties of eight composite materials. Some of the materials had the same fiber and resin matrix composition but with varying thickness. Overall, there were four material compositions. This chapter summarizes the primary conclusions of this research. Resulting material properties can be found in Tables 4.0-1, 5.0-1, 6.0-1, and 7.0-1.

The primary conclusions and recommendations with respect to the testing procedures used to determine the material properties of composite materials are as follows:

- In-plane tension properties of composite materials (elastic modulus, tensile strength, and in-plane Poisson's ratio) can be obtained adequately using ASTM D 3039/D 3039M. For some composite materials, localized failures may occur. Therefore, the specimens must have a reduced cross-sectional area along a gage length in order to control the failure location and to analyze the stress-strain results accurately.
- In-plane compression properties of composite materials (elastic modulus, compressive strength, and in-plane Poisson's ratio) can be obtained adequately using ASTM D 6641/D 6641M.
- In-plane shear properties of composite materials (shear modulus and shear strength) can be obtained adequately using ASTM D 7078/D 7078M. However, in some cases, modified fixtures are required if the strength of the materials is high.
- To obtain out-of-plane compressive strength and stiffness properties, a new testing procedure was developed in this research and was determined to obtain reliable results.
- The out-of-plane compressive test has an explosive failure mode and caution must be taken to ensure the safety of the research team.
- Out-of-plane tension properties can be obtained using ASTM D 7291/ D 7291M. Spooled specimens are recommended. In addition, when the thickness of the material is low, it is recommended to bond the material tested to end tabs using epoxy and attach the end tabs to the test fixtures.

- The epoxy used to bond materials to end tabs when performing out-of-plane tension tests is dependent on the material tested, the end tab material, and the test temperature. A two-part epoxy produced by 3M (Designation DP420, Black, with 0.25-0.50 mm beads) was found to provide the best bond for materials tested part of this research.
- Different specimen configurations are needed for different composite materials when performing out-of-plane tension tests at different temperatures since the strength at the bondline may be problematic especially when tested at high temperatures.
- For materials with small thickness and high out-of-plane tensile strengths, it may be necessary to perform out-of-plane tension tests with two different specimen geometries which measure (1) elastic properties and (2) strength properties such as for Material 3-FY09 in this research.
- Out-of-plane shear properties of composite materials (shear modulus and shear strength) can be obtained adequately using ASTM D 5379/D 5379M. For the materials tested in this research, it is necessary to bond the specimens to end tabs made from composite materials.
- Out-of-plane Poisson's ratios can be obtained using a modified version of ASTM D 7291/D 7291 M with a square cross-section and with the material tested bonded to end tabs made of composite materials. However, the research team may need to consider relatively low stress ranges to measure the elastic property since failures occur at the bondline.

The primary conclusions with respect to the experimental results using mean values of the properties of five specimens tested are as follows:

- The in-plane tensile strength and in-plane compressive strength of composite materials increase with a decrease in temperature. The in-plane tensile and compressive strength results of materials with Huntsman PolyUrethane (PU) Rencast 6405 are influenced more by temperature than materials with Applied Poleramic (API) SC-15 Epoxy.
- The in-plane tensile strength results of materials at a test temperature of 140°F are always at least 70% that at ambient temperatures. For materials with API SC-15 epoxy, the in-plane compressive strength results of materials at a temperature of 140°F are always at least 75% that at ambient. For Materials with Huntsman Rencast 6405, the in-plane compressive strength results at a temperature of 140°F are as low as 40% that at ambient.

- Overall, the in-plane compressive strength is more significantly influenced by the test temperature than the in-plane tension strength.
- The in-plane shear strength of composite materials increases with a decrease in temperature. Usually, the in-plane shear strength results of materials with Huntsman PU Rencast 6405 are more influenced by temperature than materials with Applied Poleramic (API) SC-15 Epoxy. All in-plane shear results at a temperature of 140°F are at least 55% that at ambient.
- The out-of-plane tensile strength of composite materials increases with a decrease in temperature. The out-of-plane tension results of materials with Huntsman PolyUrethane (PU) Rencast 6405 are more influenced by temperature than materials with Applied Poleramic (API) SC-15 Epoxy. However, there were some exceptions found in the data.
- The out-of-plane compressive strength of composite materials increases with a decrease in temperature. However, the test temperature does not have as significant of an influence as compared to other strength properties measured in this research. All out-of-plane compression results at a test temperature of 140°F are at least 75% that at ambient and the results do not appear to be dependent on the resin.
- The out-of-plane shear strength of composite materials increases with a decrease in temperature. For materials with API-SC-15 epoxy, the out-of-plane shear strength results at a temperature of 140°F are always at least 78% that at ambient. However, the out-of-plane shear strength at a temperature of 140°F for materials with Huntsman PU Rencast 6405 are as low as 34% that at ambient.
- The in-plane stiffness results are not as influenced by temperature as the in-plane strength results. However, the in-plane tension elastic modulus, compressive elastic modulus, and shear modulus usually decrease with an increase in temperature. For the in-plane tension modulus and the in-plane compression modulus, the results at temperatures of -40°F and 140°F are usually within 20% that at ambient temperatures.
- The in-plane shear modulus of composite materials usually increases with a decrease in temperature. The in-plane shear modulus at -40°F and 140°F is always within 20% of that

at ambient for materials with SC-15 epoxy and S2-glass. For the other materials with Huntsman Rencast 6405, the differences are as high as 35%.

- The out-of-plane tensile modulus of composite materials decreases with an increase in temperature. The comparisons are much more significant for materials with Huntsman PU Rencast 6405. For these materials, all results at a test temperature of 140°F are between 21% and 38% that at ambient which is significant. For materials with API SC-15 epoxy and S2-glass, the values are between 78% and 83% that at ambient.
- The out-of-plane compressive modulus of composite materials usually decreases with an increase in temperature. However, the results at 140°F are always at least 80% of that at ambient.
- The out-of-plane shear modulus of composite materials decreases with an increase in temperature. At a temperature of 140°F, the out-of-plane shear modulus of materials with API SC-15 epoxy is within 22% of that at ambient. At a temperature of 140°F, the out-of-plane shear modulus of materials with Huntsman Rencast 6405 is as low as 4% that at ambient which is a very unfavorable result.
- There are no direct trends in the test temperature and the resulting in-plane Poisson's ratio results (under compression and tension load). The results appear to be sporadic. However, the results at temperatures of -40°F and 140°F are usually within 20% of that at ambient. However, the in-plane Poisson's ratio of Material 6-FY09 is significantly higher at a temperature of 140°F when compared to that at 70°F.
- The out-of-plane Poisson's ratio results do not appear to be directly influenced by the test temperature. Often, the Poisson's ratio increases from test temperatures of -40°F to 70°F and decreases from test temperatures of 70°F to 140°F.
- The results with both Huntsman PU Rencast 6405 and API SC-15 epoxy indicate that the material thickness has no direct influence on the in-plane and out-of-plane strength results. The strength results obtained at a nominal material thickness of 1.5 in. or 0.75 in. are usually within 20% of the results obtained at a nominal material thickness of 1.0 in. The only outlier was the out-of-plane tension results for materials composed of API SC-15. However, the results of Material 4-FY09 (1 in. thick) are considered an outlier.

- The results of materials with both Huntsman PU Rencast 6405 and API SC-15 epoxy indicate that the material thickness has no direct influence on the in-plane and out-of-plane stiffness results. With the exception of the out-of-plane shear modulus, the results at a nominal material thickness of 1.5 in. or 0.75 in. are usually within 20% of the results obtained at a nominal material thickness of 1.0 in. Overall, the out-of-plane shear modulus results are more sporadic than other stiffness properties measured.
- The material thickness has no direct influence on the in-plane and out-of-plane Poisson's ratio results.
- The in-plane tensile strength and in-plane compressive strength of Material 3-FY09 were found to be higher than that of other materials at both ambient and elevated temperatures. The in-plane tension strength of Material 3-FY09 at 140°F is approximately two times higher than any other material.
- The material with ductile hybrid fabric results in slightly higher in-plane strength results than the equivalent material with S2-glass fibers (both with Huntsman PU Rencast 6405).
- Material 3-FY09 was found to have the highest out-of-plane tension strength due to the arrangement of aramid fibers along the z-axis.
- Materials with API-SC-15 epoxy were found to have higher out-of-plane tension strengths, out-of-plane compressive strengths, and out-of-plane shear strengths than materials with Huntsman PU Rencast 6405. The differences are more significant at a test temperature of 140°F.
- Material 6-FY09 with ductile hybrid fabric has a significantly higher in-plane tension elastic modulus than any other material tested. This material also has the highest in-plane shear modulus and in-plane compressive elastic modulus. These results are attributed to the ultra-high modulus carbon fibers which is a component of ductile hybrid fabric.
- Material 3-FY09 exhibited unique behavior when subjected to in-plane shear forces. The in-plane shear modulus was found to be very low in comparison to other materials. However, the maximum shear strains were much higher than other materials.
- Usually, materials with API SC-15 epoxy have higher out-of-plane stiffness properties (shear modulus, tensile elastic modulus, and compressive elastic modulus) than materials with Huntsman PU Rencast 6405.

- For all materials tested in this research, the in-plane tensile strength is higher than the in-plane compressive strength.
- For all materials tested in this research, the out-of-plane compressive strength is significantly higher than the out-of-plane tensile strength. The results are not comparable.
- The in-plane compressive modulus of composite materials is usually higher than the in-plane tensile modulus. For Material 6-FY09, the in-plane tension modulus was higher due to the presence of ultra-high modulus carbon fibers.
- The out-of-plane compressive modulus and the out-of-plane tensile modulus are comparable at a temperature of 70°F. However, at 140°F, the out-of-plane tensile modulus is often significantly lower than the out-of-plane compressive modulus.
- Significant variation exists in the out-of-plane Poisson's ratio results for Material 6-FY09 with respect to the ν_{xz} results and the ν_{yz} results. The ν_{yz} results are significantly higher. In some instances, the ν_{xz} results were found to be negative.

The reliability of the material testing results was analyzed by computing and comparing the coefficients of variance for each data set (results of five specimens tested to obtain each property of each material and at each temperature). Conclusions from this investigation are as follows:

- The coefficient of variance for all in-plane stiffness and strength properties is lower than 20% for all materials tested.
- The in-plane properties are less reliable at a temperature of 140°F.
- The coefficient of variance for the out-of-plane strength and stiffness properties are fairly low. All values are 27% or less with most values under 20%.
- The out-of-plane shear properties (shear modulus and shear strength) are less reliable than all other strength and stiffness results.
- With the exception of one result, the out-of-plane compressive strength results have a coefficient of variance less than 6%.
- The coefficients of variance for the in-plane and out-of-plane Poisson's ratios are often high and less reliable than the strength and stiffness properties.

- In general, the in-plane strength results for materials with SC-15 epoxy are more reliable than the results for materials with Huntsman Rencast 6405. This comparison is more significant at a temperature of 140°F.
- The out-of-plane compressive strength results are more reliable than the out-of-plane shear results and the out-of-plane tensile results.
- The in-plane stiffness results of Material 6-FY09 (DHF material) are usually less reliable than the in-plane stiffness results of the other materials tested. The in-plane stiffness results of materials with Huntsman Rencast 6405 and S2-Glass fibers are less reliable at a temperature of 140°F.
- The out-of-plane stiffness properties are less reliable at a test temperature of 140°F especially for the material with ductile hybrid fabric.
- The out-of-plane Poisson's ratio results are sometimes more reliable than the in-plane Poisson's results. However, this property was the primary measurement when performing the out-of-plane Poisson's tests.

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APPENDICES

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APPENDIX A

ACCEPTANCE TESTING FINAL RESULTS

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MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

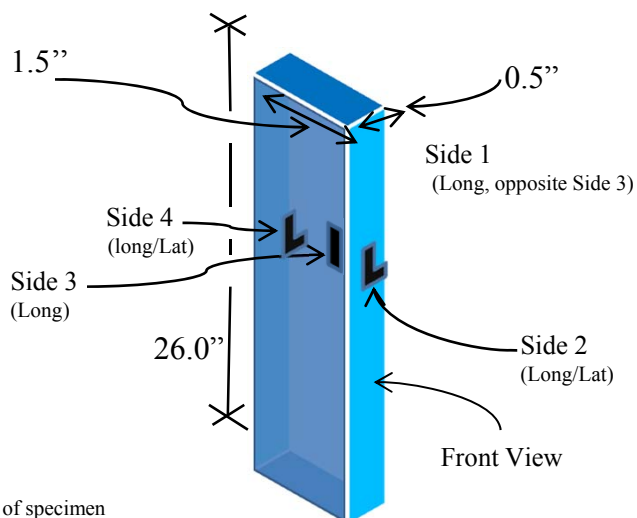
Specimen ID Group: MATA-TX-N40
Material: Huntsman Epoxy Resin 8605, DHF
Nominal Temperature: -40°F
Properties Measured: ST_x , E_x , ν_{xy}
Average Material Properties (5 Specimens):

Ultimate Load, P_x : 31,974 lbs
Tension Stress, ST_x : 41,419 psi
Tensile Modulus, E_x : 2,114,380 psi
Ultimate Strain, ϵ_x : 0.0198 in/in
Poisson Ratio, ν_{xy} : 0.2235

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain (in/in) | Poisson Ratio (ν_{xy}) | Failure Mode |
|----------------|---------------|-----------------------|--------------------------------|------------------------------|-------------------------|------------------------------|--------------|
| 1 | MATA-TX-1-N40 | 31,809 | 40,367 | 1,966,118 | 0.0206 | 0.1272 | DGM |
| 2 | MATA-TX-2-N40 | 31,854 | 39,472 | 2,244,435 | 0.0183 | 0.3604 | DGM |
| 3 | MATA-TX-3-N40 | 32,412 | 42,424 | 2,052,826 | 0.0207 | 0.1890 | DGM |
| 4 | MATA-TX-4-N40 | 31,083 | 41,444 | 2,036,408 | 0.0204 | 0.2360 | DGM |
| 5 | MATA-TX-5-N40 | 32,714 | 43,387 | 2,272,111 | 0.0192 | 0.2049 | DGM |
| Average | | 31,974 | 41,419 | 2,114,380 | 0.0198 | 0.2235 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. Fibers are generally oriented in two dimensions. For this test, load is applied parallel the plane of the fibers at a test rate is 0.05 in/min. The test is performed on the Instron 8502A, which has a universal joint that is attached to the upper head to allow for universal tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

-40°F Test Condition**Specimen Dimensions, Strain Gauges****Notes:**

- 1) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 2) See A-2 to A-6 for individual specimen results

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MATA-TX-1-N40**
 Test Date: 10/15/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , v_{xy}

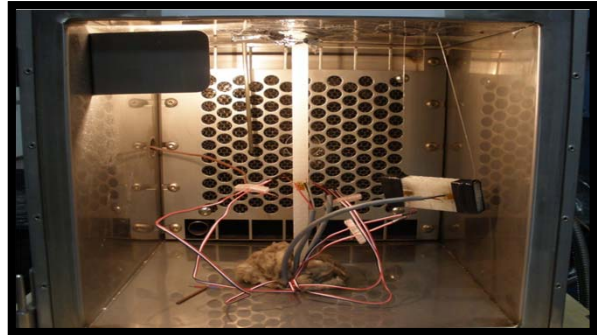
Average Material Properties:

Ultimate Load, P_x : 31,809 lbs
 Tension Stress, ST_x : 40,367 psi
 Tensile Modulus, E_x : 1,966,118 psi
 Ultimate Strain, ϵ_x : 0.0206 in/in
 Poisson Ratio, v_{xy} : 0.1272

Measured/Nominal Specimen Dimensions:

Width, W: 1.468(1.50) in
 Thickness, H: 0.531(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,362 lbs
 50% Max Load: 15,905 lbs

PICTURE OF SPECIMEN PRE-TEST



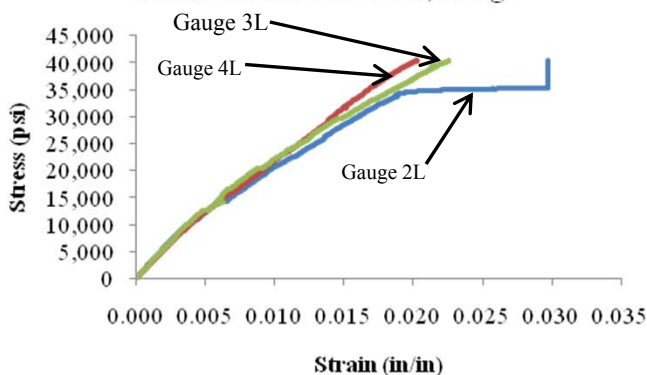
PICTURE OF SPECIMEN POST-TEST



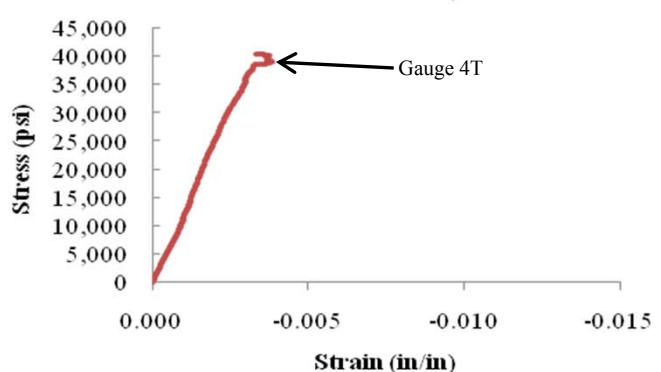
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | Lost Gauge | Lost Gauge | Lost Gauge | 4T | -0.0016 | -0.0007 | 0.1272 |
| 2L | 0.0097 | 0.0031 | 1,779,664 | | | | |
| 3L | 0.0092 | 0.0029 | 1,980,292 | | | | |
| 4L | 0.0086 | 0.0033 | 2,138,399 | | | | |
| Average | | | 1,966,118 | Average | | | 0.1272 |

Stress-Strain Curve 2A, Long.



Stress-Strain Curve 2A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MATA-TX-2-N40**
 Test Date: 11/22/2010
 Specimen Rcvd.: 11/05/2010
 Properties Measured: ST_x , E_x , v_{xy}

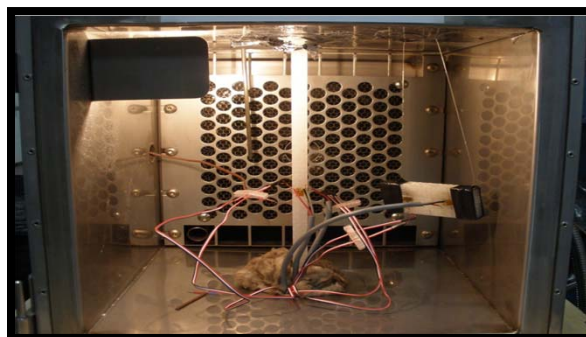
Average Material Properties:

Ultimate Load, P_x : 31,854 lbs
 Tension Stress, ST_x : 39,472 psi
 Tensile Modulus, E_x : 2,244,435 psi
 Ultimate Strain, ϵ_x : 0.0183 in/in
 Poisson Ratio, v_{xy} : 0.2740

Measured/Nominal Specimen Dimensions:

Width, W: 1.519(1.50) in
 Thickness, H: 0.531(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,371 lbs
 50% Max Load: 15,927 lbs

PICTURE OF SPECIMEN PRE-TEST



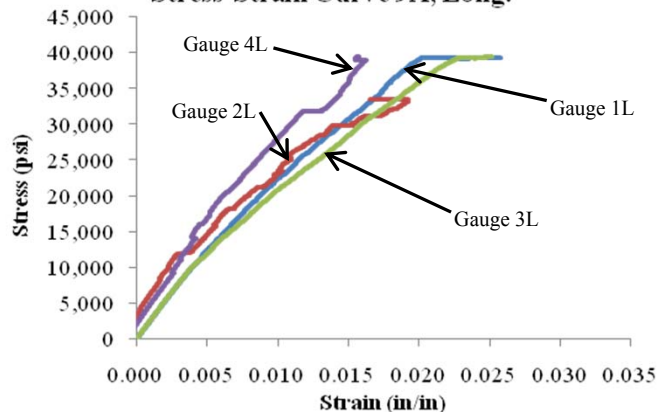
PICTURE OF SPECIMEN POST-TEST



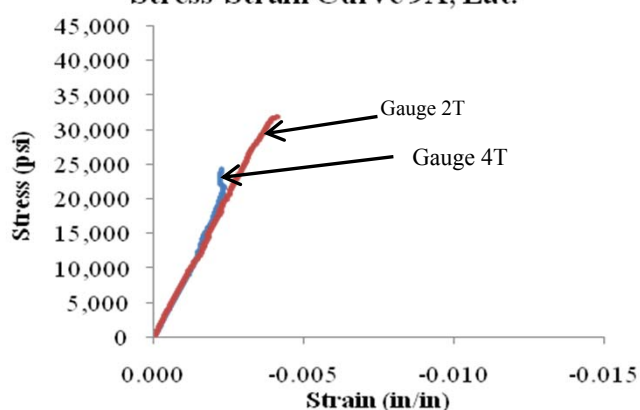
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|--|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0086 | 0.0030 | 2,135,208 | 2T | -0.0022 | -0.0010 | 0.1877 |
| 2L | 0.0077 | 0.0015 | 1,935,583 | 4T | -0.0024 | -0.0010 | 0.3604 |
| 3L | 0.0094 | 0.0030 | 1,860,072 | Note: Lateral Gauges were placed on both thickness sides which allowed for an averaged Poisson's ratio in the 'x,y' plane. | | | |
| 4L | 0.0060 | 0.0021 | 3,046,876 | | | | |
| Average | | | 2,244,435 | Average | | | 0.2740 |

Stress-Strain Curve 9A, Long.



Stress-Strain Curve 9A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MATA-TX-3-N40
 Test Date: 11/22/2010
 Specimen Rcvd.: 11/05/2010
 Properties Measured: ST_x , E_x , v_{xy}

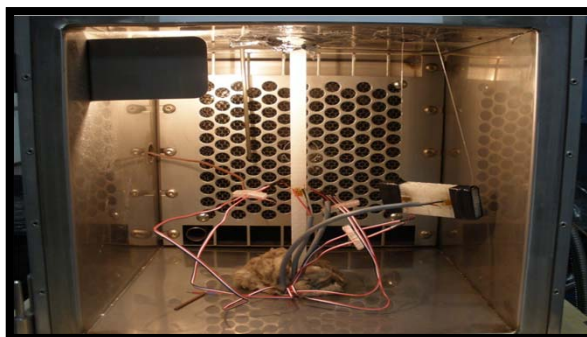
Average Material Properties:

Ultimate Load, P_x : 32,412 lbs
 Tension Stress, ST_x : 42,424 psi
 Tensile Modulus, E_x : 2,052,826 psi
 Ultimate Strain, ϵ_x : 0.0207 in/in
 Poisson Ratio, v_{xy} : 0.1890

Measured/Nominal Specimen Dimensions:

Width, W: 1.498(1.50) in
 Thickness, H: 0.510(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,482 lbs
 50% Max Load: 16,206 lbs

PICTURE OF SPECIMEN PRE-TEST



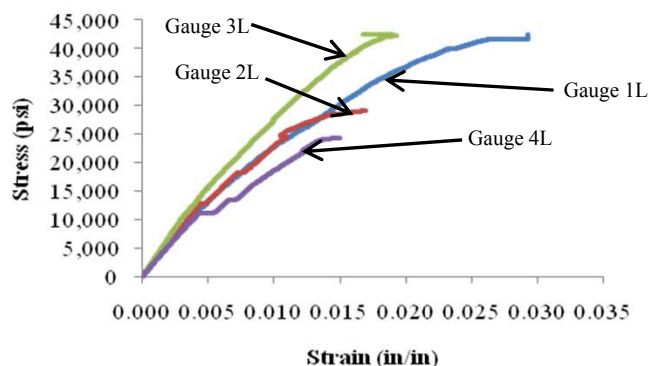
PICTURE OF SPECIMEN POST-TEST



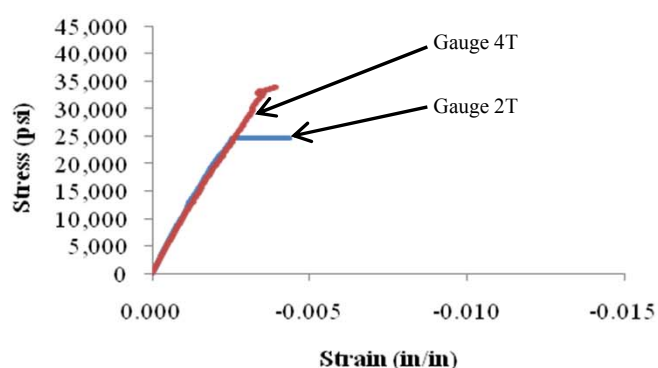
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|--|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0091 | 0.0029 | 2,081,272 | 2T | -0.0021 | -0.0008 | 0.2137 |
| 2L | 0.0092 | 0.0029 | 2,024,381 | 4T | -0.0022 | -0.0008 | 0.1641 |
| 3L | 0.0073 | 0.0025 | 2,630,897 | Note: Lateral Gauges were placed on both thickness sides which allowed for an averaged Poisson's ratio in the 'x,y' plane. | | | |
| 4L | 0.0118 | 0.0032 | 1,483,460 | | | | |
| Average | | | 2,055,002 | Average | | | 0.1890 |

Stress-Strain Curve 10A, Long.



Stress-Strain Curve 10A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST

Individual Specimen Test Summary

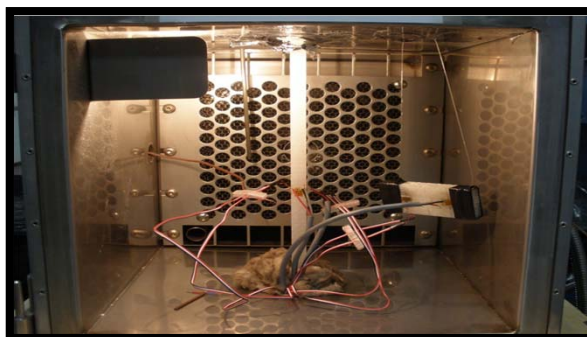
Specimen ID: **MATA-TX-4-N40**
 Test Date: 11/23/2010
 Specimen Rcvd.: 11/05/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 31,083 lbs
 Tension Stress, ST_x : 41,444 psi
 Tensile Modulus, E_x : 2,036,408 psi
 Ultimate Strain, ϵ_x : 0.0204 in/in
 Poisson Ratio, v_{xy} : 0.2360

Measured/Nominal Specimen Dimensions:

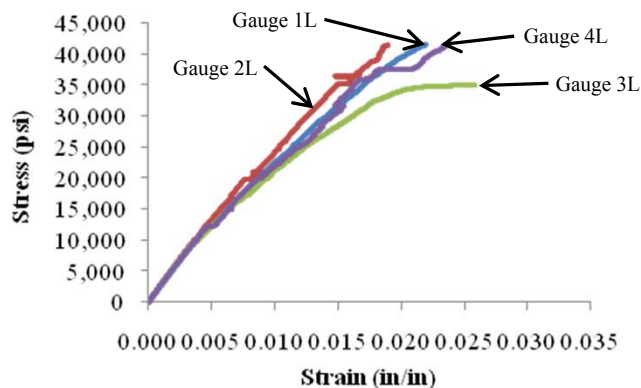
Width, W: 1.500(1.50) in
 Thickness, H: 0.500(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load 6,217 lbs
 50% Max Load: 15,542 lbs



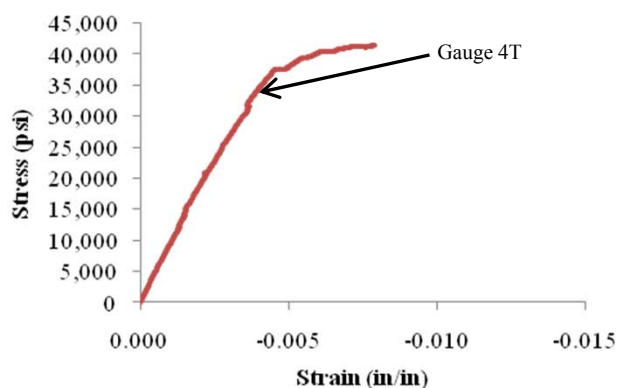
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0091 | 0.0031 | 2,060,594 | 4T | -0.0022 | -0.0009 | 0.2186 |
| 2L | 0.0085 | 0.0030 | 2,228,900 | | | | |
| 3L | 0.0097 | 0.0030 | 1,855,394 | | | | |
| 4L | 0.0093 | 0.0031 | 2,000,745 | | | | |
| Average | | | 2,036,408 | Average | | | 0.2186 |

Stress-Strain Curve 11A, Long.



Stress-Strain Curve 11A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MATA-TX-5-N40
 Test Date: 11/29/2010
 Specimen Rcvd.: 11/05/2010
 Properties Measured: ST_x , E_x , v_{xy}

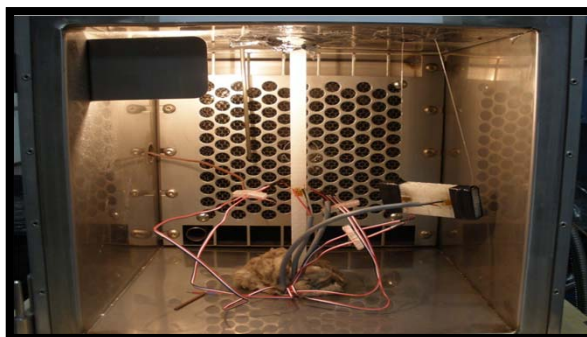
Average Material Properties:

Ultimate Load, P_x : 32,714 lbs
 Tension Stress, ST_x : 43,387 psi
 Tensile Modulus, E_x : 2,272,111 psi
 Ultimate Strain, ϵ_x : 0.0192 in/in
 Poisson Ratio, v_{xy} : 0.2049

Measured/Nominal Specimen Dimensions:

Width, W: 1.501(1.50) in
 Thickness, H: 0.502(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,543 lbs
 50% Max Load: 16,357 lbs

PICTURE OF SPECIMEN PRE-TEST



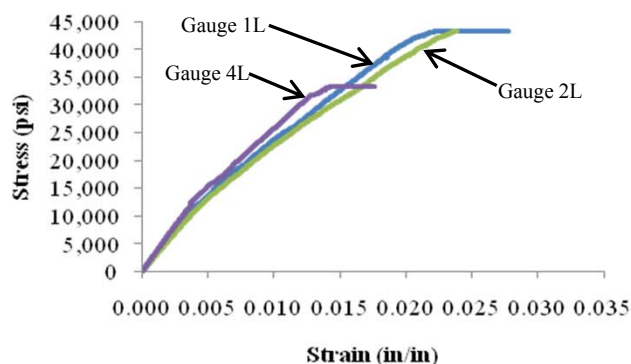
PICTURE OF SPECIMEN POST-TEST



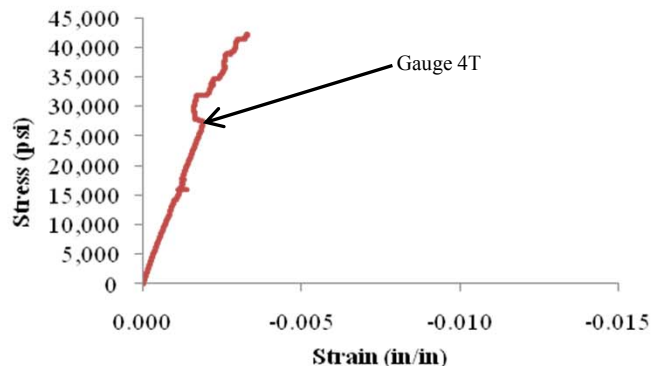
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0089 | 0.0029 | 2,148,899 | 4T | -0.0015 | -0.0006 | 0.1685 |
| 2L | 0.0079 | 0.0027 | 2,481,187 | | | | |
| 3L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| 4L | 0.0081 | 0.0026 | 2,389,244 | | | | |
| Average | | | 2,272,111 | Average | | | 0.1685 |

Stress-Strain Curve 12A, Long.



Stress-Strain Curve 12A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

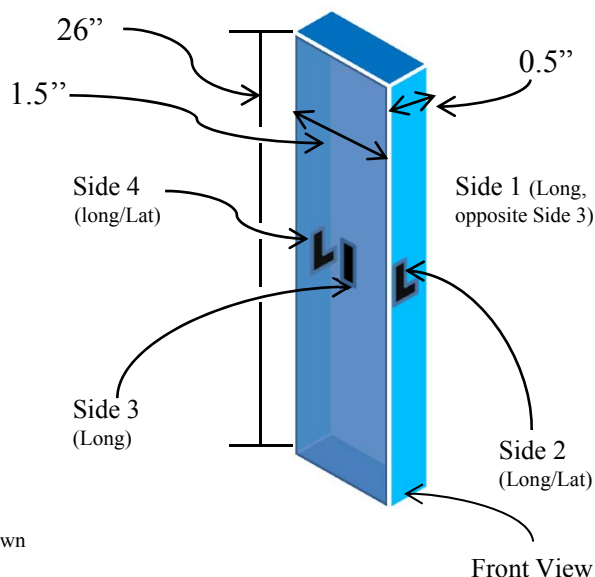
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MATA-TX-70**
 Material: **Huntsman Epoxy Resin 8605, DHF**
 Nominal Temperature: **70°F**
 Properties Measured: **ST_x , E_x , v_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : **32,373 lbs**
 Tensile Stress, ST_x : **42,732 psi**
 Tensile Modulus, E_x : **2,461,795 psi**
 Ultimate Strain, ϵ_x : **0.018 in/in**
 Poisson Ratio, v_{xy} : **0.213**

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain (in/in) | Poisson Ratio (v_{xy}) | Failure Mode |
|----------------|--------------|-----------------------|--------------------------------|------------------------------|-------------------------|----------------------------|--------------|
| 1 | MATA-TX-1-70 | 30,684 | 41,467 | 2,328,367 | 0.018 | 0.245 | Ten Delam |
| 2 | MATA-TX-2-70 | 30,530 | 41,871 | 2,603,779 | 0.016 | 0.204 | Ten Delam |
| 3 | MATA-TX-3-70 | 32,182 | 42,647 | 2,686,174 | 0.016 | 0.150 | Ten Delam |
| 4 | MATA-TX-4-70 | 34,006 | 43,336 | 2,420,125 | 0.018 | 0.213 | Ten Delam |
| 5 | MATA-TX-5-70 | 33,964 | 44,340 | 2,270,530 | 0.020 | 0.254 | Ten Delam |
| Average | | 32,273 | 42,732 | 2,461,795 | 0.018 | 0.213 | |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. Fibers are generally oriented in two dimensions. For this test, load is applied parallel the plane of the fibers at a test rate is 0.05 in/min. The test is performed on the Instron 8502A, which has a universal joint that is attached to the upper head to allow for universal tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

Ambient Temp. Test Cond.**Specimen Dimensions, Strain Gauges****Notes:**

- 1) Twelve specimens tested at ambient (70F), group of five representative data sets shown
- 2) See A-8 to A-12 for individual specimens results
- 3) "Ten Delam" represents "Tensile Delamination" as mode of specimen failure

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST



Individual Specimen Test Summary

Specimen ID: **MATA-TX-1-70**
 Test Date: 9/3/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,684 lbs
 Tension Stress, ST_x : 41,467 psi
 Tensile Modulus, E_x : 2,328,367 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson Ratio, ν_{xy} : 0.245

Measured/Nominal Specimen Dimensions:

Width, W: 1.47(1.50) in
 Thickness, H: 0.50(0.50) in

Laboratory Temperature: 70°F

Failure Mode: Tensile Delamination

20% Max Load 6,137 lbs

50% Max Load: 15,342 lbs

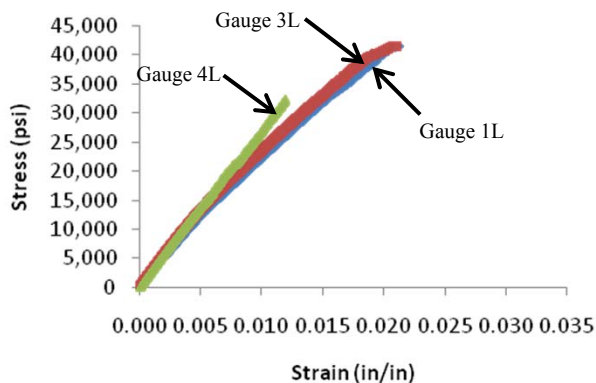
PICTURE OF SPECIMEN POST-TEST



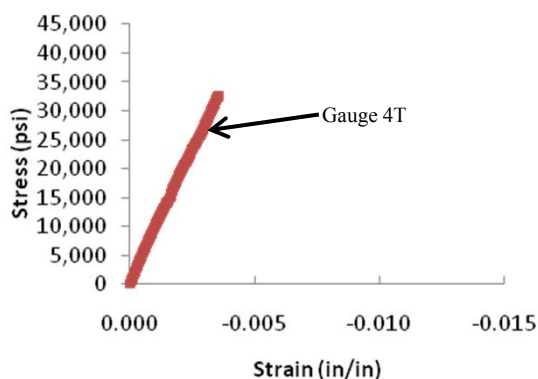
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0093 | 0.0033 | 2,086,538 | 4T | -0.00062 | -0.00082 | 0.2454 |
| 2L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| 3L | 0.0086 | 0.0030 | 2,112,802 | | | | |
| 4L | 0.0075 | 0.0029 | 1,786,894 | | | | |
| Average | 0.0085 | 0.0031 | 2,132,063 | | | | |

Stress-Strain Curve 1A, Long.



Stress-Strain Curve 1A, Lat.



Engineering Test notes:

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST



Individual Specimen Test Summary

Specimen ID: MATA-TX-2-70
 Test Date: 9/4/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,530 lbs
 Tension Stress, ST_x : 41,871 psi
 Tensile Modulus, E_x : 2,603,779 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson Ratio, ν_{xy} : 0.2035

Measured/Nominal Specimen Dimensions:

Width, W: 1.48(1.50) in
 Thickness, H: 0.49(0.50) in

Laboratory Temperature: 70°F

Failure Mode: Tensile Delamination

20% Max Load 6,106 lbs

50% Max Load: 15,265 lbs

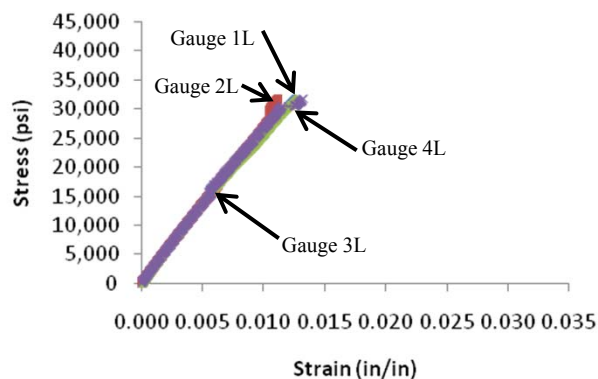
PICTURE OF SPECIMEN POST-TEST



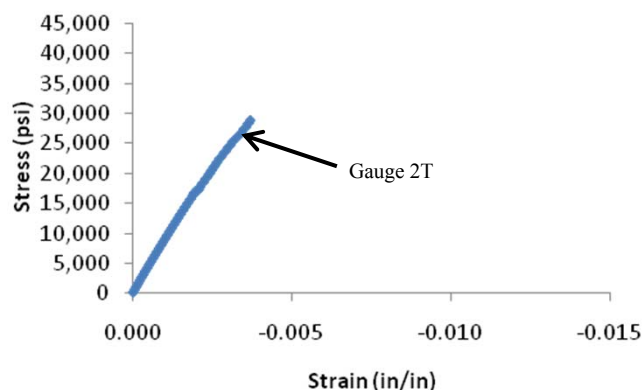
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0078 | 0.0029 | 2,550,670 | 2T | -0.0025 | -0.000935 | 0.2035 |
| 2L | 0.0078 | 0.0030 | 2,640,550 | | | | |
| 3L | 0.0079 | 0.0029 | 2,520,525 | | | | |
| 4L | 0.0077 | 0.0030 | 2,703,372 | | | | |
| Average | 0.0078 | 0.0030 | 2,603,779 | | | | |

Stress-Strain Curve 2A, Long.



Stress-Strain Curve 2A, Lat.



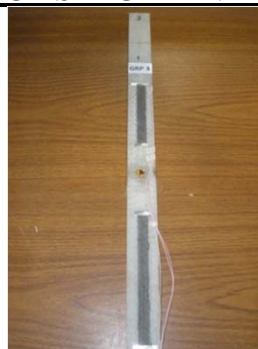
Engineering Test notes:

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST



Individual Specimen Test Summary

Specimen ID: MATA-TX-3-70
 Test Date: 9/6/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 32,182 lbs
 Tension Stress, ST_x : 42,647 psi
 Tensile Modulus, E_x : 2,686,174 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson Ratio, ν_{xy} : 0.1496

Measured/Nominal Specimen Dimensions:

Width, W: 1.47(1.50) in
 Thickness, H: 0.51(0.50) in

Laboratory Temperature: 70°F

Failure Mode: Tensile Delamination

20% Max Load 6,436 lbs

50% Max Load: 16,091 lbs

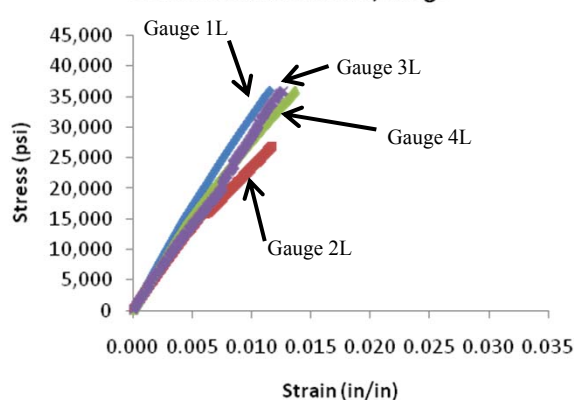
PICTURE OF SPECIMEN POST-TEST



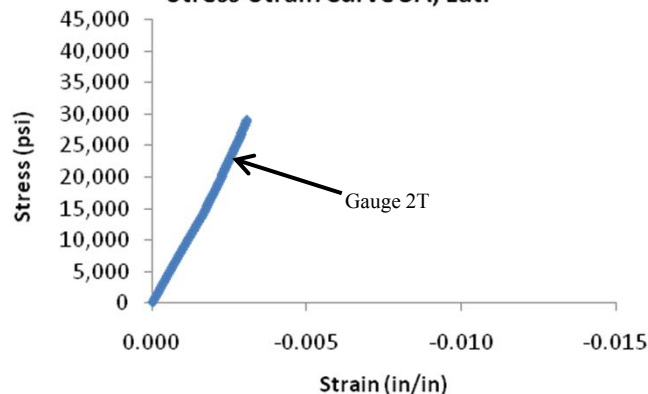
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0064 | 0.0024 | 3,188,770 | 2T | -0.0023 | -0.00097 | 0.1496 |
| 2L | 0.0090 | 0.0030 | 2,135,169 | | | | |
| 3L | 0.0072 | 0.0026 | 2,735,349 | | | | |
| 4L | 0.0077 | 0.0029 | 1,685,408 | | | | |
| Average | 0.0076 | 0.0027 | 2,686,174 | | | | |

Stress-Strain Curve 3A, Long.



Stress-Strain Curve 3A, Lat.



Engineering Test notes:

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST



Individual Specimen Test Summary

Specimen ID: MATA-TX-4-70
 Test Date: 9/10/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 34,006 lbs
 Tension Stress, ST_x : 43,336 psi
 Tensile Modulus, E_x : 2,420,125 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson Ratio, ν_{xy} : 0.2126

Measured/Nominal Specimen Dimensions:

Width, W: 1.48(1.50) in
 Thickness, H: 0.53(0.50) in

Laboratory Temperature: 70°F

Failure Mode: Tensile Delamination

20% Max Load 6,801 lbs

50% Max Load: 17,003 lbs

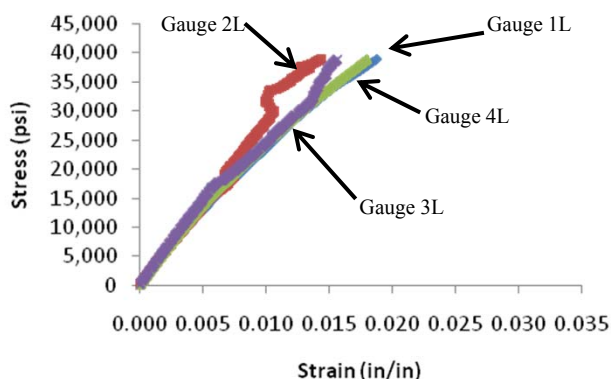
PICTURE OF SPECIMEN POST-TEST



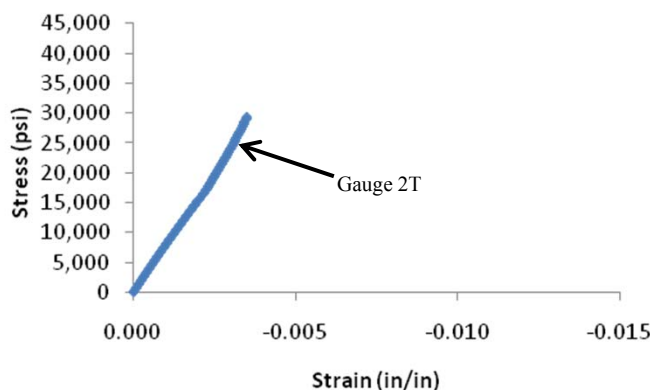
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0091 | 0.0033 | 2,235,239 | 2T | -0.0027 | -0.0011 | 0.2126 |
| 2L | 0.0077 | 0.0031 | 2,850,218 | | | | |
| 3L | 0.0086 | 0.0030 | 2,318,306 | | | | |
| 4L | 0.0086 | 0.0029 | 2,276,737 | | | | |
| Average | 0.0085 | 0.0031 | 2,420,125 | | | | |

Stress-Strain Curve 4A, Long.



Stress-Strain Curve 4A, Lat.



Engineering Test notes:

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MATA-TX-5-70**
 Test Date: 11/29/2010
 Specimen Rcvd.: 11/5/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 33,964 lbs
 Tension Stress, ST_x : 44,340 psi
 Tensile Modulus, E_x : 2,270,530 psi
 Ultimate Strain, ϵ_x : 0.0179 in/in
 Poisson Ratio, ν_{xy} : 0.2359

Measured/Nominal Specimen Dimensions:

Width, W: 1.51(1.50) in
 Thickness, H: 0.51(0.50) in

Laboratory Temperature: 70°F

Failure Mode: Tensile Delamination

20% Max Load 6,793 lbs

50% Max Load: 16,982 lbs

PICTURE OF SPECIMEN PRE-TEST



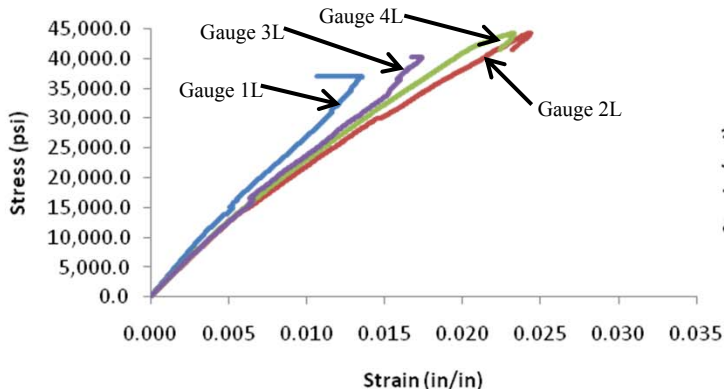
PICTURE OF SPECIMEN POST-TEST



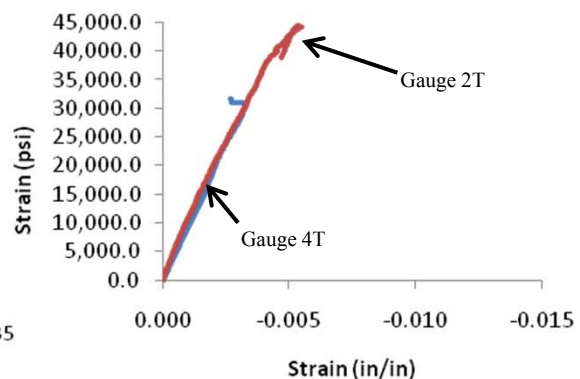
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0080 | 0.0028 | 2,594,908 | 2T | -0.00229 | -0.00096 | 0.2177 |
| 2L | 0.0101 | 0.0035 | 1,994,853 | 4T | -0.00224 | -0.00079 | 0.2541 |
| 3L | 0.0095 | 0.0034 | 2,168,417 | Average | | | 0.2359 |
| 4L | 0.0091 | 0.0034 | 2,323,943 | | | | |
| Average | 0.0092 | 0.0033 | 2,270,530 | | | | |

Stress-Strain Curve Sample 5A, Long.



Stress-Strain Curve Sample 5A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

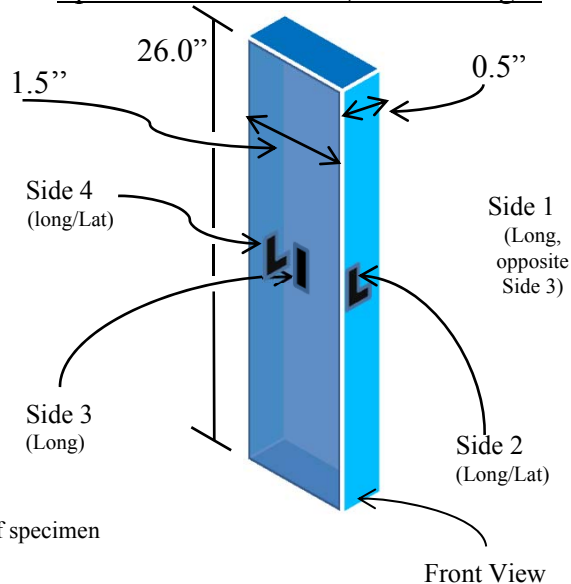
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-TX-140
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: 140°F
 Properties Measured: ST_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 29,403 lbs
 Tension Stress, ST_x : 38,160 psi
 Tensile Modulus, E_x : 2,363,494 psi
 Ultimate Strain, ϵ_x : 0.0166 in/in
 Poisson Ratio, ν_{xy} : 0.2358

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain (in/in) | Poisson Ratio (ν_{xy}) | Failure Mode |
|---------|---------------|-----------------------|--------------------------------|------------------------------|-------------------------|------------------------------|--------------|
| 1 | MATA-TX-1-140 | 29,373 | 37,682 | 2,132,063 | 0.01788 | - | DGM |
| 2 | MATA-TX-2-140 | 30,798 | 39,510 | 2,352,104 | 0.01723 | 0.30786 | DGM |
| 3 | MATA-TX-3-140 | 30,088 | 38,600 | 2,495,868 | 0.01609 | 0.18379 | DGM |
| 4 | MATA-TX-4-140 | 29,148 | 37,393 | 2,446,519 | 0.01543 | 0.18359 | DGM |
| 5 | MATA-TX-5-140 | 27,610 | 37,615 | 2,390,918 | 0.01635 | 0.26828 | DGM |
| Average | | 29,403 | 38,160 | 2,363,494 | 0.0166 | 0.2358 | - |

Test Description:

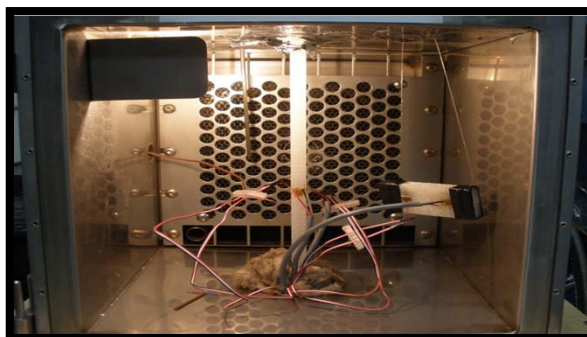
The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. Fibers are generally oriented in two dimensions. For this test, load is applied parallel to one fiber orientation (either 'x' or 'y'.) Since the fibers are orientated in the zero and ninety degree orientation, the 'x' and 'y' properties are theoretically the same. The test rate is 0.05 in/min. The test is performed on the Instron 8502A, which has a universal joint that is attached to the upper head to allow for universal tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

Envir. Chamber Test Cond.**Specimen Dimensions, Strain Gauges****Notes:**

- 1) 13 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See A-14 thru A-18 for individual specimen results

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Individual Specimen Test Summary

Specimen ID: MATA-TX-1-140
 Test Date: 10/5/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 29,373 lbs
 Tension Stress, ST_x : 37,682 psi
 Tensile Modulus, E_x : 2,132,063 psi
 Ultimate Strain, ϵ_x : 0.0179 in/in
 Poisson Ratio, ν_{xy} : 0.2651

Measured/Nominal Specimen Dimensions:

Width, W : 1.47(1.50) in
 Thickness, H : 0.53(0.50) in

Laboratory Temperature: 68°F

Failure Mode: DGM

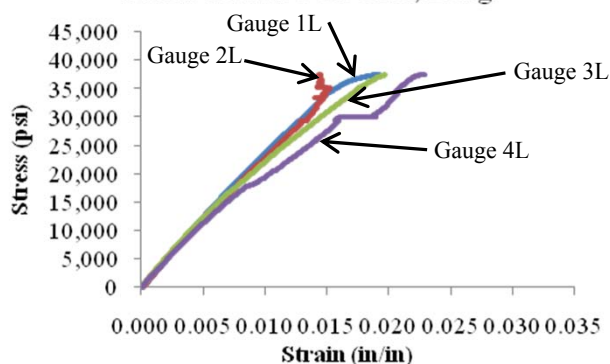
20% Max Load 5,875 lbs

50% Max Load: 15,399 lbs

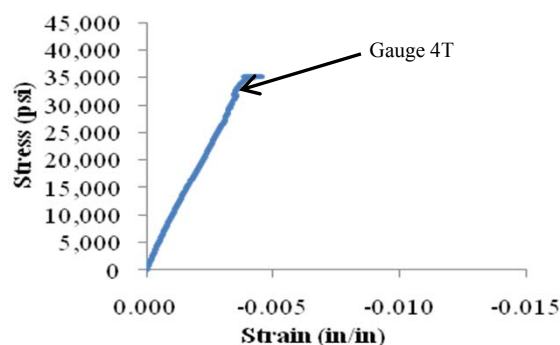
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0077 | 0.0029 | 2,390,538 | 4T | -0.0021 | -0.0007 | 0.2651 |
| 2L | 0.0080 | 0.0030 | 2,238,017 | | | | |
| 3L | 0.0083 | 0.0030 | 2,112,802 | | | | |
| 4L | 0.0096 | 0.0033 | 1,786,894 | | | | |
| Average | | | 2,132,063 | Average | | | 0.2651 |

Stress-Strain Curve 1A, Long.



Stress-Strain Curve 1A, Lat.



Engineering Test notes:

*Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MATA-TX-2-140
 Test Date: 10/07/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,798 lbs
 Tension Stress, ST_x : 39509.58 psi
 Tensile Modulus, E_x : 2,352,104 psi
 Ultimate Strain, ϵ_x : 0.0172 in/in
 Poisson Ratio, v_{xy} : 0.3079

Measured/Nominal Specimen Dimensions:

Width, W: 1.47(1.50) in
 Thickness, H: 0.53(0.50) in

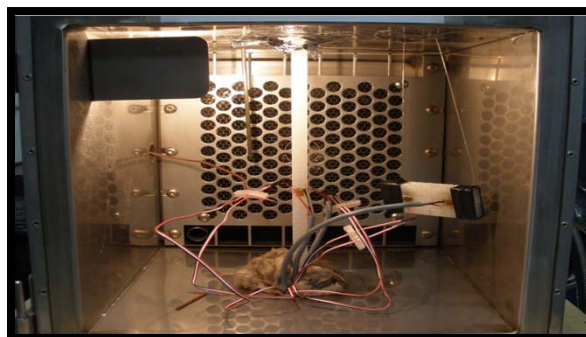
Laboratory Temperature: 68°F

Failure Mode: DGM

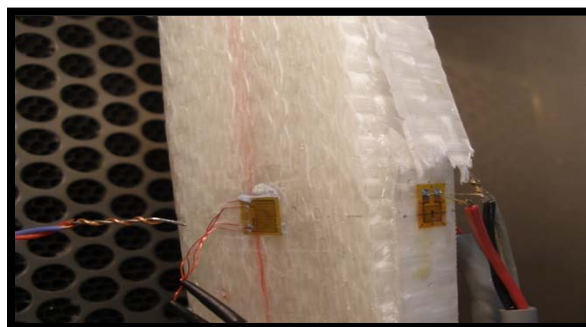
20% Max Load 6159 lbs

50% Max Load: 15,399 lbs

PICTURE OF SPECIMEN PRE-TEST



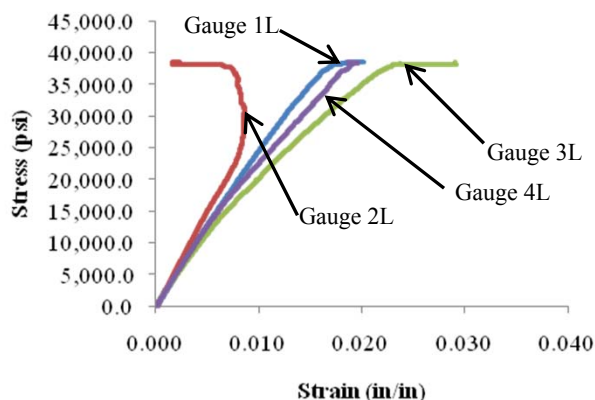
PICTURE OF SPECIMEN POST-TEST



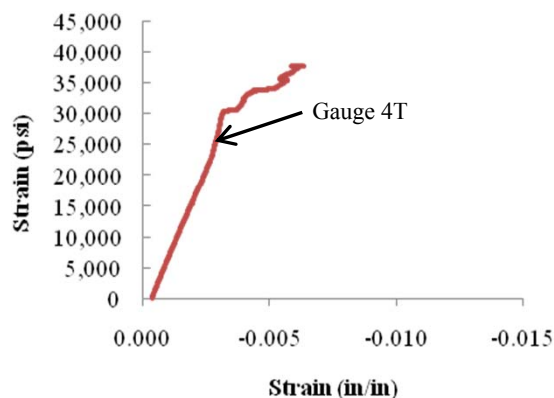
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|--------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0078 | 0.0029 | 2,453,816 | 4T | -0.0021 | -0.0008 | 0.3079 |
| 2L | 0.0066 | 0.0025 | 2,886,083 | | | | |
| 3L | 0.0097 | 0.0033 | 1,858,117 | | | | |
| 4L | 0.0084 | 0.0031 | 2,210,399 | | | | |
| Average | | | 2,352,104 | Average | | | 0.3079 |

Stress-Strain Curve 2A, Long.



Stress-Strain Curve 2A, Lat.



Engineering Test notes:

*Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MATA-TX-3-140**
 Test Date: 10/08/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,088 lbs
 Tension Stress, ST_x : 38,600 psi
 Tensile Modulus, E_x : 2,495,868 psi
 Ultimate Strain, ϵ_x : 0.0172 in/in
 Poisson Ratio, v_{xy} : 0.3079

Measured/Nominal Specimen Dimensions:

Width, W: 1.48(1.50) in
 Thickness, H: 0.53(0.50) in

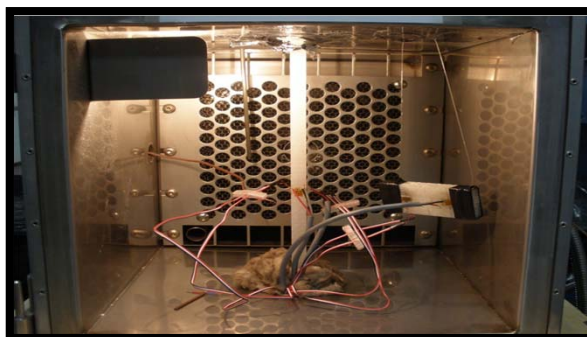
Laboratory Temperature: 68°F

Failure Mode: DGM

20% Max Load 6,018 lbs

50% Max Load: 15,044 lbs

PICTURE OF SPECIMEN PRE-TEST



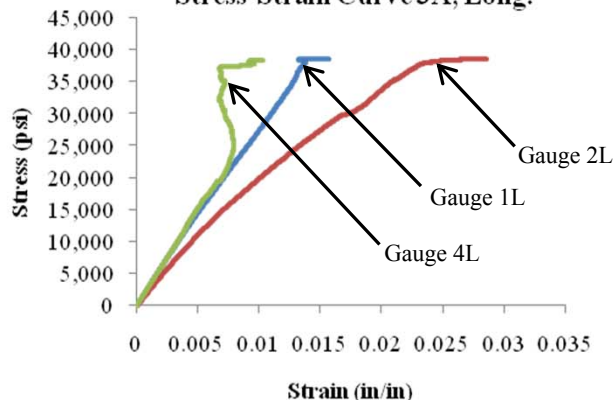
PICTURE OF SPECIMEN POST-TEST



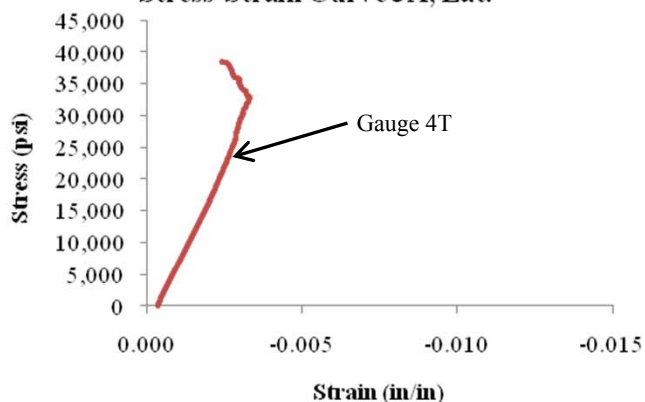
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | 0.0068 | 0.0025 | 2,729,707 | 4T | -0.0019 | -0.0007 | 0.1838 |
| 2L | 0.0096 | 0.0033 | 1,849,423 | | | | |
| 3L | Lost | Lost | Lost | | | | |
| 4L | 0.0066 | 0.0026 | 2,908,473 | | | | |
| Average | | | 2,495,868 | Average | | | 0.1838 |

Stress-Strain Curve 3A, Long.



Stress-Strain Curve 3A, Lat.



Engineering Test notes:

*Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MAT1-TX-4-140
 Test Date: 10/11/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 29,148 lbs
 Tension Stress, ST_x : 37393.39 psi
 Tensile Modulus, E_x : 2,446,519 psi
 Ultimate Strain, ϵ_x : 0.0154 in/in
 Poisson Ratio, ν_{xy} : 0.1835

Measured/Nominal Specimen Dimensions:

Width, W: 1.47 (1.50) in
 Thickness, H: 0.53 (0.50) in

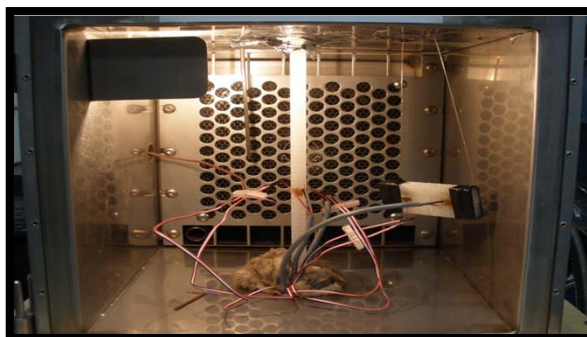
Laboratory Temperature: 68°F

Failure Mode: DGM

20% Max Load 5,830 lbs

50% Max Load: 14,574 lbs

PICTURE OF SPECIMEN PRE-TEST



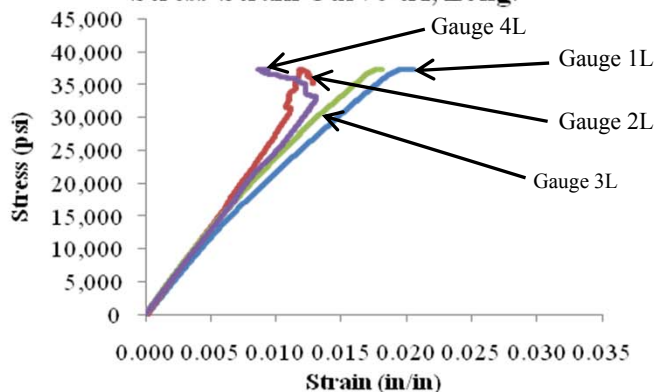
PICTURE OF SPECIMEN POST-TEST



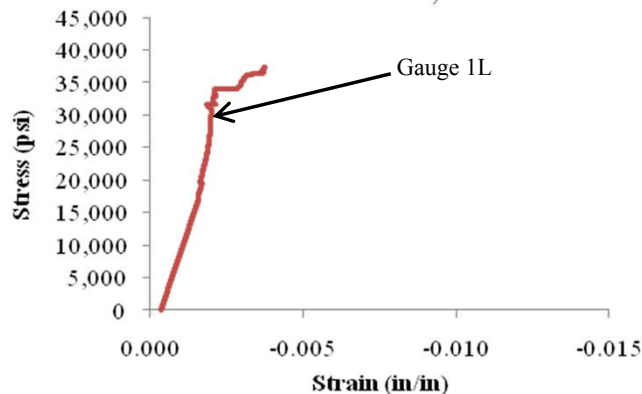
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0084 | 0.0032 | 2,125,102 | 4T | -0.0016 | -0.0009 | 0.1836 |
| 2L | 0.0069 | 0.0028 | 2,755,095 | | | | |
| 3L | 0.0075 | 0.0027 | 2,353,702 | | | | |
| 4L | 0.0072 | 0.0028 | 2,552,177 | | | | |
| Average | | | 2,446,519 | Average | | | 0.1836 |

Stress-Strain Curve 4A, Long.



Stress-Strain Curve 4A, Lat.



Engineering Test notes:

*Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges

*Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-140**
 Test Date: 10/11/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 27,610 lbs
 Tension Stress, ST_x : 37615.38 psi
 Tensile Modulus, E_x : 2,390,918 psi
 Ultimate Strain, ϵ_x : 0.0163 in/in
 Poisson Ratio, ν_{xy} : 0.2683

Measured/Nominal Specimen Dimensions:

Width, W: 1.47 (1.50) in
 Thickness, H: 0.50 (0.50) in

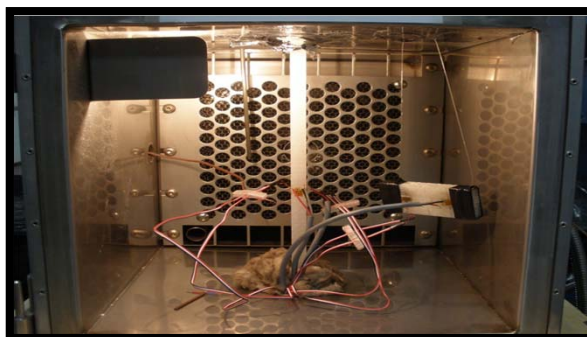
Laboratory Temperature: 68°F

Failure Mode: DGM

20% Max Load 5,522 lbs

50% Max Load: 13,805 lbs

PICTURE OF SPECIMEN PRE-TEST



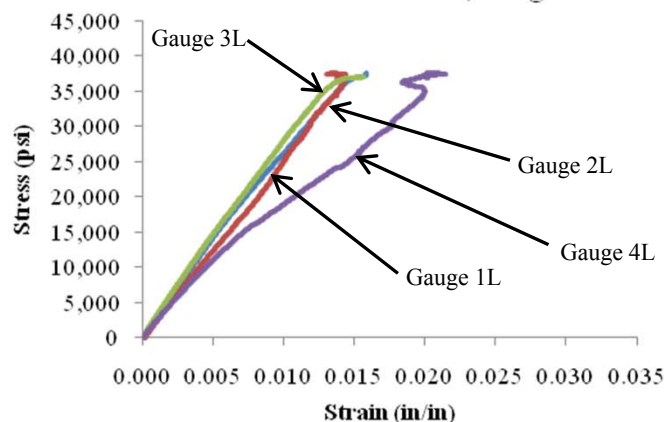
PICTURE OF SPECIMEN POST-TEST



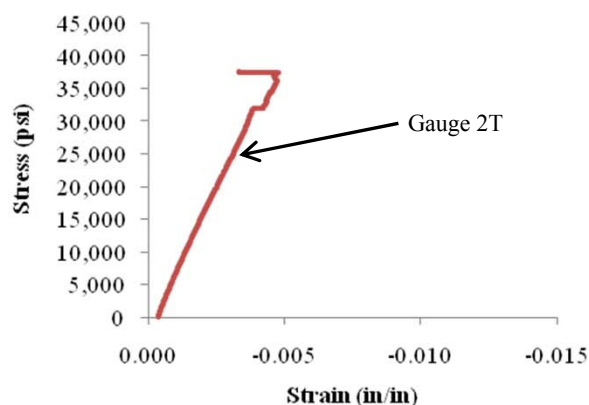
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | 0.0068 | 0.0027 | 2,728,841 | 4T | -0.0024 | -0.0011 | 0.2683 |
| 2L | 0.0078 | 0.0030 | 2,372,429 | | | | |
| 3L | 0.0066 | 0.0025 | 2,762,792 | | | | |
| 4L | 0.0099 | 0.0033 | 1,699,608 | | | | |
| Average | | | 2,390,918 | Average | | | 0.2683 |

Stress-Strain Curve 5A, Long.



Stress-Strain Curve 5A, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 125-UW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-CX-N40
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: -40°F
 Properties Measured: SC_x , E_x , ν_{xy}

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 57,178 | lbs |
| Compressive Strength, SC_x : | 37,155 | psi |
| Compressive Modulus, E_x : | 2,953,429 | psi |
| Ultimate Strain, ϵ_x : | 0.013 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.283 | |

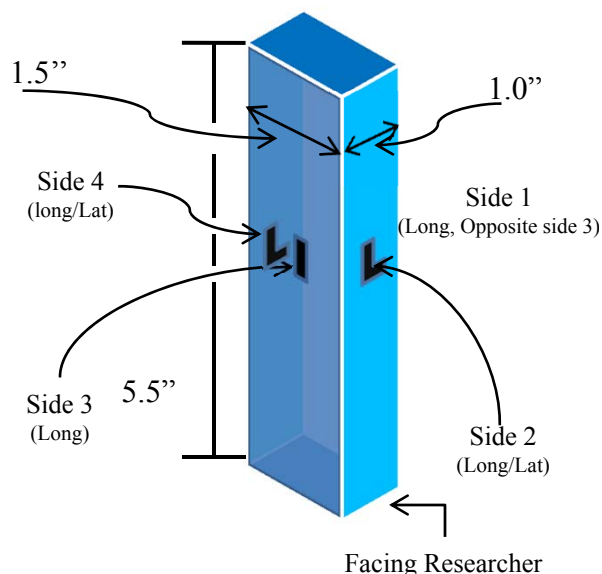
| Sample | Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|----------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MATA- CX-1-N40 | 51,075 | 34,534 | 2,603,799 | 0.013 | 0.280 | Delam |
| 2 | MATA- CX-2-N40 | 65,622 | 41,480 | 2,902,448 | 0.015 | 0.245 | Delam |
| 3 | MATA- CX-3-N40 | 53,317 | 36,074 | 2,938,532 | 0.012 | 0.285 | Delam |
| 4 | MATA- CX-4-N40 | 56,317 | 35,871 | 3,301,690 | 0.011 | 0.279 | Delam |
| 5 | MATA- CX-5-N40 | 59,560 | 37,816 | 3,020,676 | 0.013 | 0.324 | Delam |
| Average | | 57,178 | 37,155 | 2,953,429 | 0.013 | 0.283 | |

Test Description:

The In-Plane Compression Test performed in accordance with ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

-40°F Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See A-20 to A-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

Specimen Dimensions, Strain Gauges

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-1-N40**

Test Date: 2/16/2011

Specimen Received: 11/19/2010

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 51,075 | lbs |
| Compressive Strength, SC_x : | 35,534 | psi |
| Compressive Modulus, E_x : | 2,603,799 | psi |
| Ultimate Strain, ϵ_x : | 0.013 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.280 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|--------------|-----|
| Width, W: | 1.55(1.50) | in |
| Thickness, H: | 0.96(1.00) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Delamination | |
| 20% Max Load | 10,215 | lbs |
| 50% Max Load: | 25,538 | lbs |

PICTURE OF SPECIMEN PRE-TEST



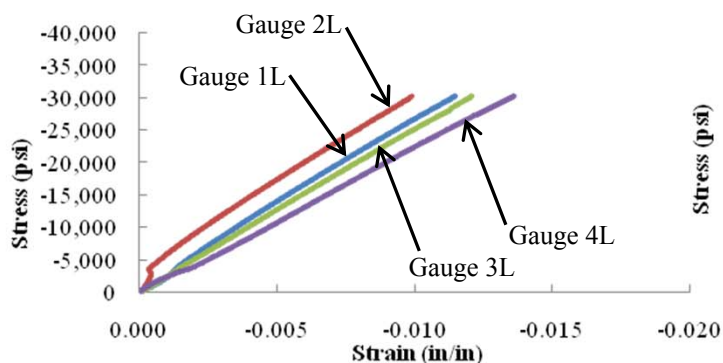
PICTURE OF SPECIMEN POST-TEST



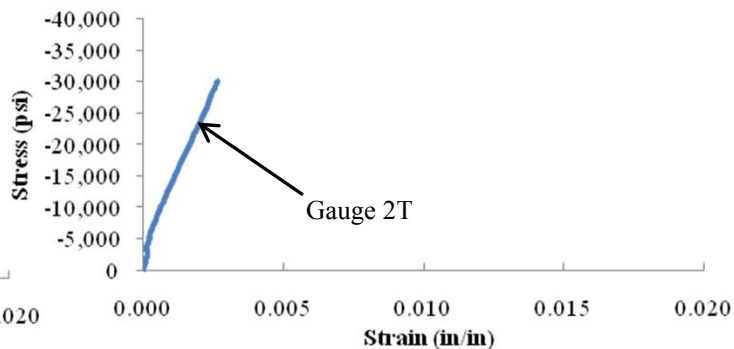
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|--|--|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0062 | -0.0024 | 2,691,490 | 2T | -0.0014 | -0.0003 | 0.280 |
| 2L | -0.0050 | -0.0013 | 2,841,688 | 4T | Lost Gauge | Lost Gauge | Lost Gauge |
| 3L | -0.0068 | -0.0028 | 2,542,696 | | | | |
| 4L | -0.0078 | -0.0033 | 2,339,322 | | | | |
| Average | | | 2,603,799 | | | | 0.280 |

Stress-Strain Curve N40_01,Long



Stress-Strain Curve N40_01,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-1-N40**

Test Date: 2/17/2011

Specimen Received: 11/5/2010

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 65,622 | lbs |
| Compressive Strength, SC_x : | 41,480 | psi |
| Compressive Modulus, E_x : | 2,902,448 | psi |
| Ultimate Strain, ϵ_x : | 0.015 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.245 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|--------------|-----|
| Width, W: | 1.57(1.50) | in |
| Thickness, H: | 1.01(1.00) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Delamination | |
| 20% Max Load | 13,124 | lbs |
| 50% Max Load: | 32,811 | lbs |

PICTURE OF SPECIMEN PRE-TEST



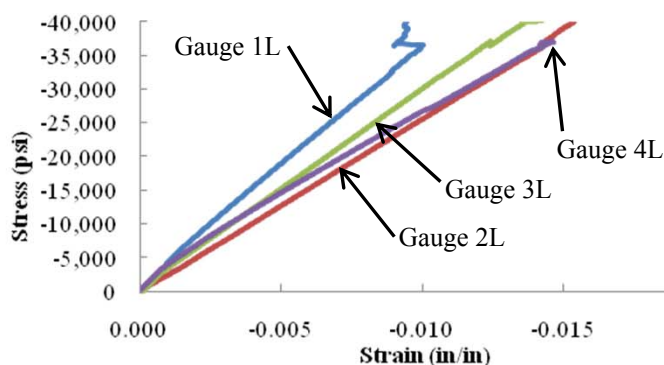
PICTURE OF SPECIMEN POST-TEST



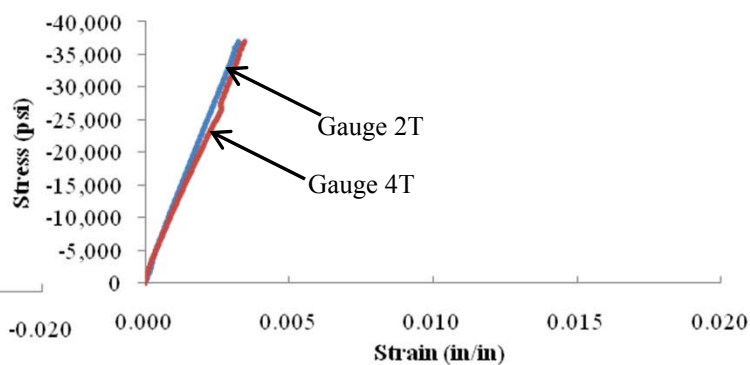
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|--|--|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0055 | -0.0020 | 3,564,242 | 2T | 0.0018 | 0.0007 | 0.231 |
| 2L | -0.0081 | -0.0033 | 3,590,950 | 4T | 0.0020 | 0.0007 | 0.259 |
| 3L | -0.0069 | -0.0027 | 2,955,338 | | | | |
| 4L | -0.0075 | -0.0025 | 2,499,260 | | | | |
| Average | | | 2,902,448 | | | | 0.245 |

Stress-Strain Curve N40_02,Long



Stress-Strain Curve N40_02,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-3-N40**
 Test Date: 2/17/2011
 Specimen Received: 11/19/2010
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 53,317 lbs
 Compressive Strength, SC_x : 36,074 psi
 Compressive Modulus, E_x : 2,938,532 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.285

Measured/Nominal Specimen Dimensions:

Width, W: 1.55(1.50) in
 Thickness, H: 0.96 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load 10,663 lbs
 50% Max Load: 26,658 lbs

PICTURE OF SPECIMEN PRE-TEST



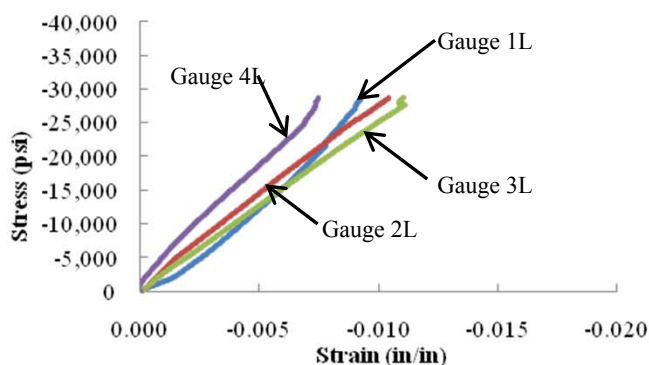
PICTURE OF SPECIMEN POST-TEST



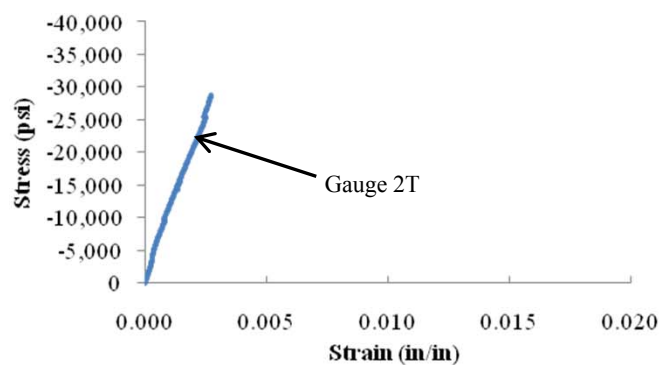
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0068 | -0.0034 | 3,167,244 | 2T | 0.0017 | 0.0006 | 0.285 |
| 2L | -0.0063 | -0.0023 | 2,755,591 | 4T | Lost Gauge | Lost Gauge | - |
| 3L | -0.0071 | -0.0028 | 2,547,066 | | | | |
| 4L | -0.0048 | -0.0015 | 3,284,226 | | | | |
| Average | | | 2,938,552 | | | | 0.285 |

Stress-Strain Curve N40_03,Long



Stress-Strain Curve N40_03,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-4-N40**
 Test Date: 2/23/2011
 Specimen Received: 11/5/2010
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 56,317 lbs
 Compressive Strength, SC_x : 35,871 psi
 Compressive Modulus, E_x : 3,301,690 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.279

Measured/Nominal Specimen Dimensions:

Width, W: 1.55(1.50) in
 Thickness, H: 1.01(1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 11,263 lbs
 50% Max Load: 28,159 lbs

PICTURE OF SPECIMEN PRE-TEST



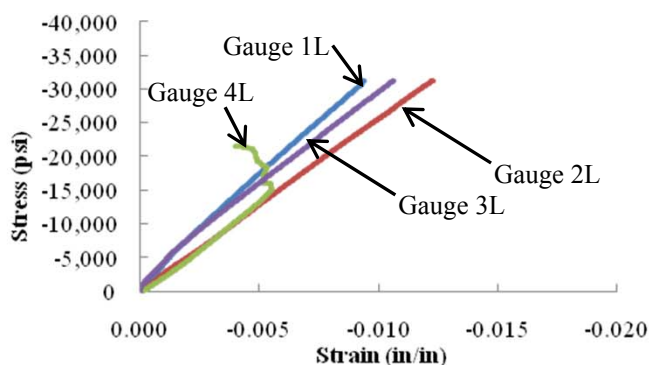
PICTURE OF SPECIMEN POST-TEST



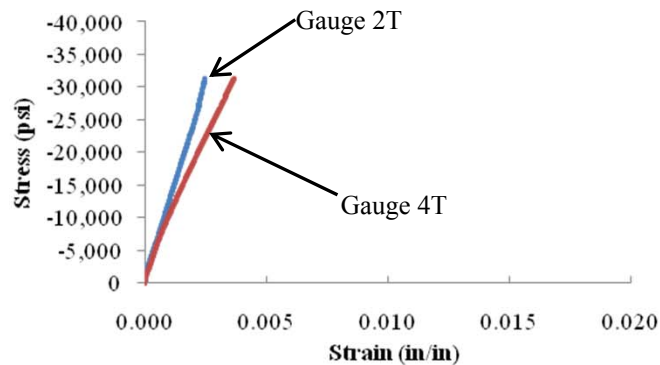
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0051 | -0.0018 | 3,248,149 | 2T | 0.0015 | 0.0006 | 0.222 |
| 2L | -0.0069 | -0.0028 | 2,630,177 | 4T | 0.0015 | 0.0006 | 0.335 |
| 3L | -0.0053 | -0.0029 | 4,547,909 | | | | |
| 4L | -0.0057 | -0.0018 | 2,780,526 | | | | |
| Average | | | 3,301,690 | | | | 0.279 |

Stress-Strain Curve N40_04,Long



Stress-Strain Curve N40_04,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-5-N40**
 Test Date: 2/23/11
 Specimen Received: 11/19/10
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 59,560 lbs
 Compressive Strength, SC_x : 37,816 psi
 Compressive Modulus, E_x : 2,865,290 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.355

Measured/Nominal Specimen Dimensions:

Width, W: 1.55(1.50) in
 Thickness, H: 1.03(1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load 10,107 lbs
 50% Max Load: 25,268 lbs

PICTURE OF SPECIMEN PRE-TEST



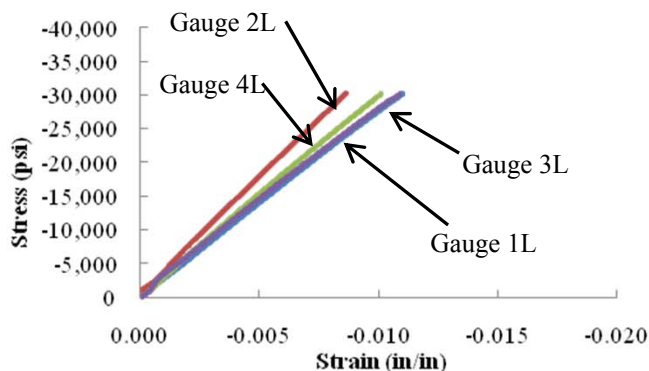
PICTURE OF SPECIMEN POST-TEST



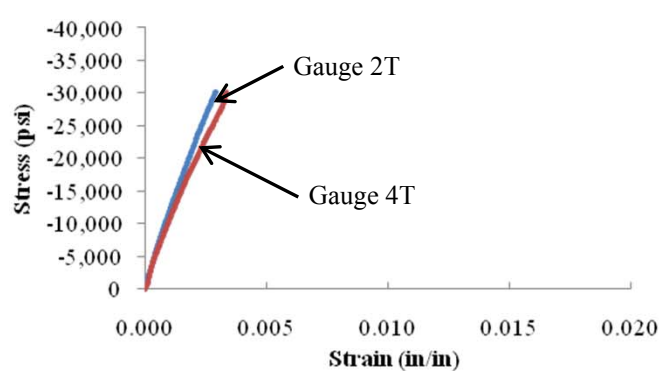
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0067 | -0.0027 | 2,811,938 | 2T | 0.0017 | 0.0006 | 0.330 |
| 2L | -0.0053 | -0.0020 | 3,446,641 | 4T | 0.0020 | 0.0007 | 0.318 |
| 3L | -0.0062 | -0.0024 | 3,027,297 | | | | |
| 4L | -0.0065 | -0.0025 | 2,796,827 | | | | |
| Average | | | 3,020,676 | | | | 0.324 |

Stress-Strain Curve N40_05, Long



Stress-Strain Curve N40_05, Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

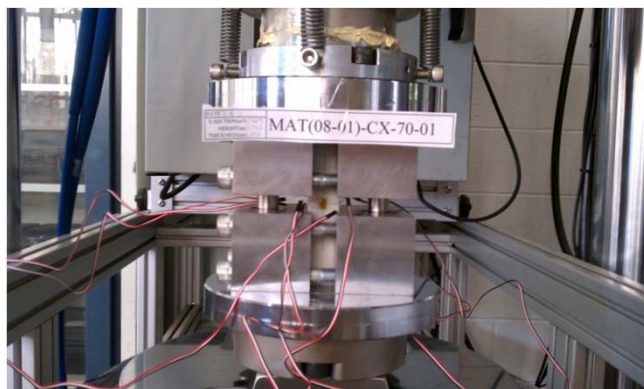
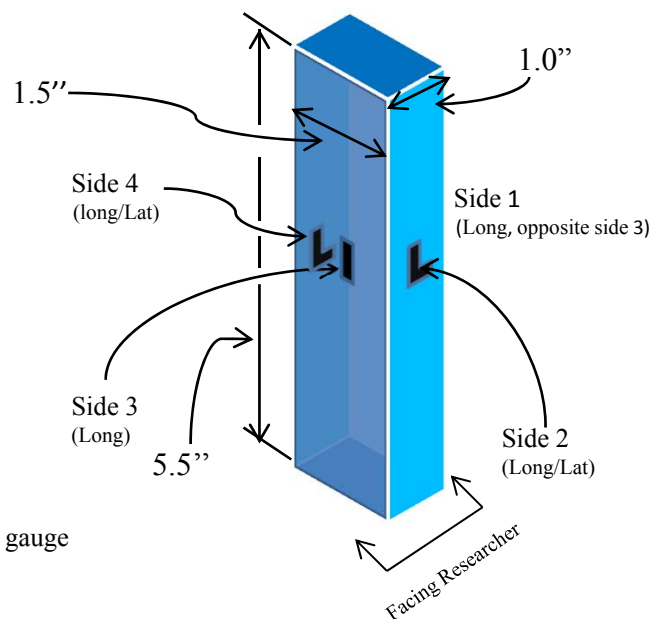
Specimen ID Group: MATA-CX-70
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: 70°F
 Properties Measured: SC_x , E_x , ν_{xy}

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 57,493 | lbs |
| Tension Stress, ST_x : | 39,480 | psi |
| Tensile Modulus, E_x : | 2,018,169 | psi |
| Ultimate Strain, ϵ_x : | 0.013 | in/in |
| Poisson Ratio, ν_{xy} : | 0.28 | |

| Sample | Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain (in/in) | Poisson's Ratio (ν_{xy}) | Failure Mode |
|---------|--------------|-----------------------|------------------------------------|----------------------------------|-------------------------|--------------------------------|--------------|
| 1 | MATA-CX-1-70 | 55,770 | 35,888 | 2,902,947 | 0.012 | - | HGM |
| 2 | MATA-CX-2-70 | 54,763 | 38,457 | 2,705,461 | 0.014 | 0.287 | HGM |
| 3 | MATA-CX-3-70 | 57,360 | 40,281 | 3,077,371 | 0.013 | - | HGM |
| 4 | MATA-CX-4-70 | 59,062 | 41,476 | 3,087,806 | 0.014 | - | HGM |
| 5 | MATA-CX-5-70 | 58,806 | 41,297 | 3,230,326 | 0.013 | 0.274 | HGM |
| Average | | 57,493 | 39,480 | 3,000,782 | 0.013 | 0.280 | |

Test Description:

The In-Plane Compression Test per ASTM D6641 measures the in-plane compressive strength, compressive modulus, and in-plane Poisson ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are theoretically the same. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

Ambient Temp. Test Cond.Specimen Dimensions, Strain GaugesNotes:

- 1) Reference A-26 to A-30 for individual specimen information.
- 2) Failure mode HGM refers to a through-thickness failure at the gauge section in the middle of the specimen. (Ref ASTM D 3410)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-1-70**
 Test Date: 7/10/2010
 Specimen Rcvd.: 6/25/2010
 Properties Measured: SC_x , E_x , ν_{xy}

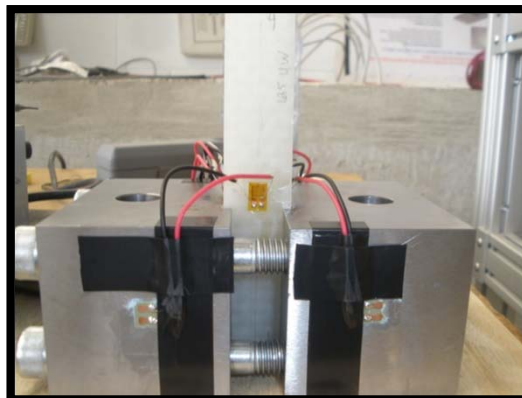
Average Material Properties:

Ultimate Load, P_x : 55,770 lbs
 Compressive Strength, SC_x : 35,888 psi
 Compressive Modulus, E_x : 2,902,947 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : Lost Gauge

Measured/Theoretical Specimen Dimensions:

Width, W: 1.465 (1.50) in
 Thickness, H: 0.970 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Shear
 20% Max Load: 27,885 lbs
 50% Max Load: 11,154 lbs

PICTURE OF SPECIMEN PRE-TEST



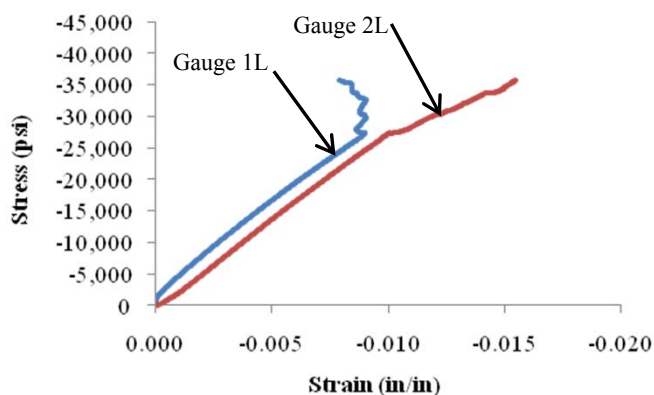
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0054 | -0.0018 | 2,934,736 | 1T | Lost Gauge | Lost Gauge | Lost Gauge |
| 2L | -0.0065 | -0.0028 | 2,878,640 | 2T | Lost Gauge | Lost Gauge | Lost Gauge |
| 3L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| 4L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| Average | | | 2,906,688 | | | | |

Stress-Strain Curve 1A Long.



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-2-70**
 Test Date: 7/12/2010
 Specimen Rcvd.: 6/24/2010
 Properties Measured: SC_x , E_x , ν_{xy}

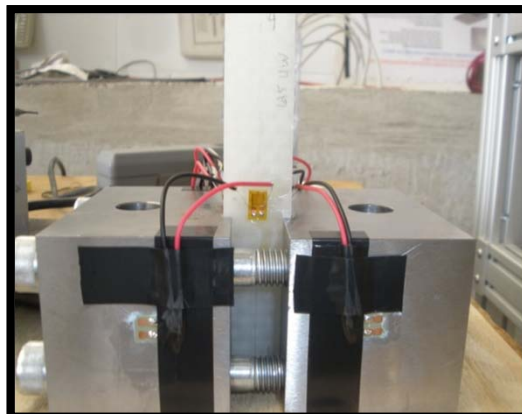
Average Material Properties:

Ultimate Load, P_x : 54,763 lbs
 Compressive Strength, SC_x : 38,457 psi
 Compressive Modulus, E_x : 2,705,461 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.287

Measured/Theoretical Specimen Dimensions:

Width, W: 1.468 (1.50) in
 Thickness, H: 0.970 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Shear
 20% Max Load: 27,382 lbs
 50% Max Load: 10,953 lbs

PICTURE OF SPECIMEN PRE-TEST



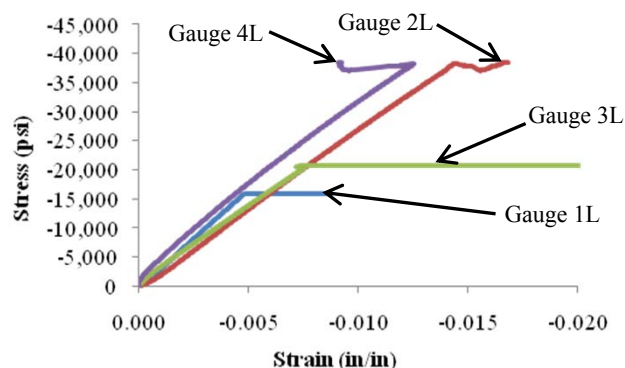
PICTURE OF SPECIMEN POST-TEST



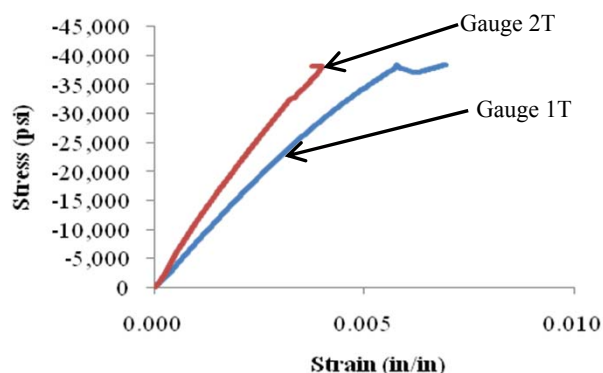
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0075 | -0.0024 | 2,255,680 | 1T | 0.0025 | 0.0010 | 0.2976 |
| 2L | -0.0071 | -0.0031 | 2,837,695 | 2T | 0.0018 | 0.0007 | 0.2757 |
| 3L | -0.0071 | -0.0026 | 2,588,523 | Average | | | 0.2866 |
| 4L | -0.0055 | -0.0018 | 3,139,947 | | | | |
| Average | | | 2,705,461 | | | | |

Stress-Strain Curve 2A, Long.



Stress-Strain Curve Sample 2A, Lat.



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-3-70**
 Test Date: 7/15/2010
 Specimen Rcvd.: 6/24/2010
 Properties Measured: SC_x , E_x , ν_{xy}

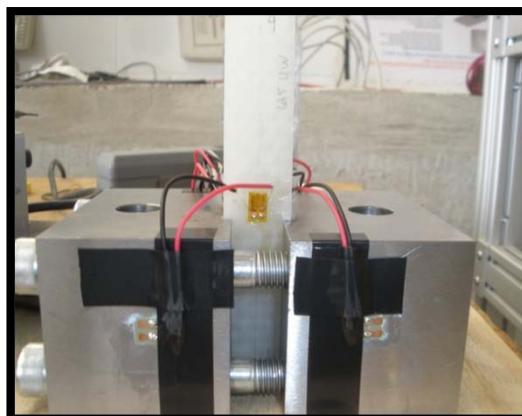
Average Material Properties:

Ultimate Load, P_x : 57,360 lbs
 Compressive Strength, SC_x : 40,281 psi
 Compressive Modulus, E_x : 3,077,371 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.446

Measured/Theoretical Specimen Dimensions:

Width, W: 1.467 (1.50) in
 Thickness, H: 0.970 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Shear
 20% Max Load: 28,680 lbs
 50% Max Load: 11,472 lbs

PICTURE OF SPECIMEN PRE-TEST



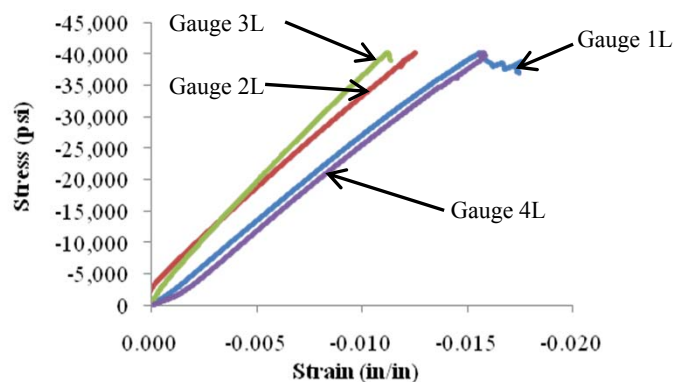
PICTURE OF SPECIMEN POST-TEST



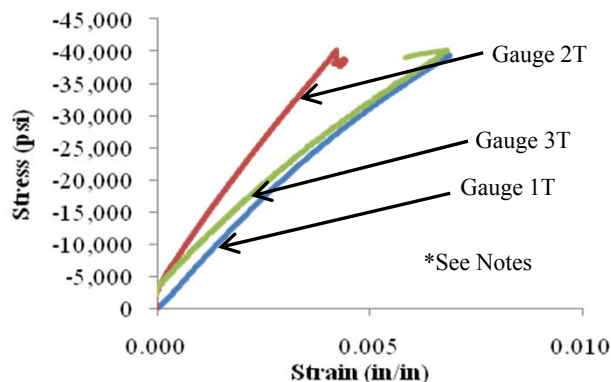
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0055 | -0.0015 | 3,072,916 | 1T | 0.0030 | 0.0011 | -0.4249 |
| 2L | -0.0051 | -0.0018 | 3,625,961 | 2T | 0.0018 | 0.0005 | -0.3302 |
| 3L | -0.0080 | -0.0037 | 2,820,739 | 3T | 0.0026 | 0.0007 | -0.5825 |
| 4L | -0.0074 | -0.0031 | 2,789,867 | Average | | | -0.4459 |
| Average | | | 3,077,371 | | | | |

Stress-Strain Curve 3A, Long.



Stress-Strain Curve 3A, Lat.



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Three lateral gages will not be used for further testing. Information regarding strain gage location missing.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-4-70**
 Test Date: 7/16/2010
 Specimen Rcvd.: 6/24/2010
 Properties Measured: SC_x , E_x , ν_{xy}

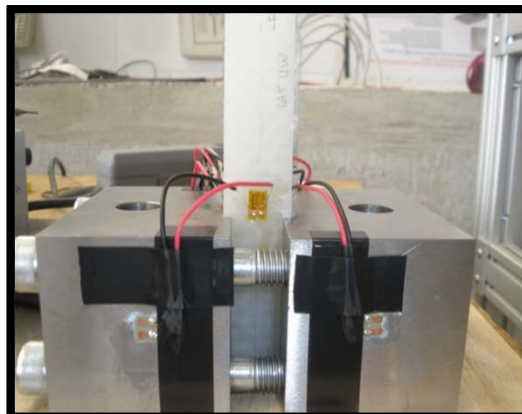
Average Material Properties:

Ultimate Load, P_x : 59,062 lbs
 Compressive Strength, SC_x : 41,476 psi
 Compressive Modulus, E_x : 3,087,806 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.359

Measured/Theoretical Specimen Dimensions:

Width, W: 1.458(1.50) in
 Thickness, H: 1.004 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Shear
 20% Max Load: 29,531 lbs
 50% Max Load: 11,812 lbs

PICTURE OF SPECIMEN PRE-TEST



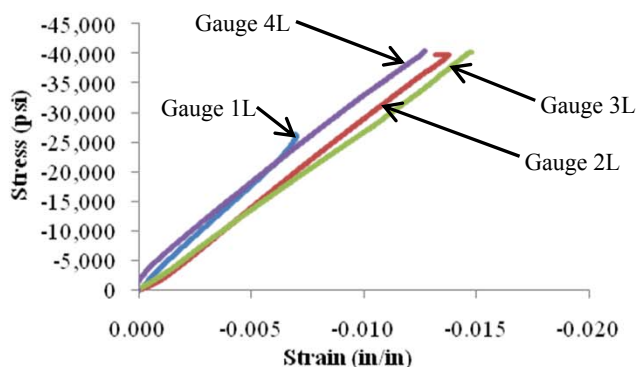
PICTURE OF SPECIMEN POST-TEST



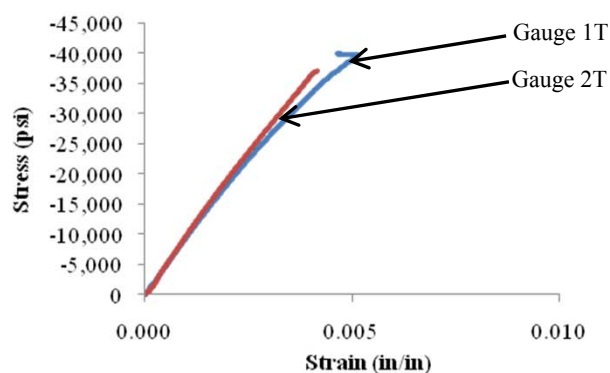
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0072 | -0.0032 | 3,109,992 | 1T | 0.0023 | 0.0009 | -0.4249 |
| 2L | -0.0077 | -0.0031 | 2,712,791 | 2T | 0.0022 | 0.0009 | -0.3302 |
| 3L | -0.0058 | -0.0018 | 3,088,462 | Average | | | 0.3776 |
| 4L | -0.0059 | -0.0022 | 3,439,980 | | | | |
| Average | | | 3,087,806 | | | | |

Stress-Strain Curve 4A, Long.



Stress-Strain Curve 4A, Lat.



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-5-70**
 Test Date: 7/20/2010
 Specimen Rcvd.: 6/24/2010
 Properties Measured: SC_x , E_x , ν_{xy}

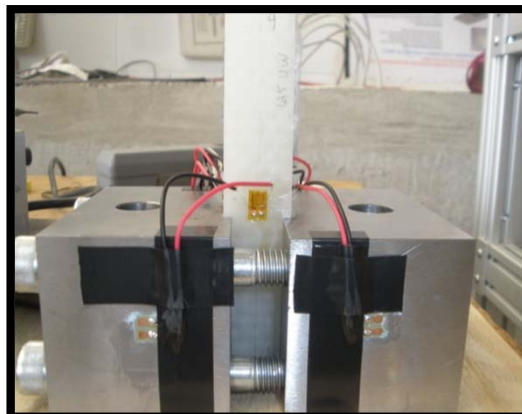
Average Material Properties:

Ultimate Load, P_x : 58,806 lbs
 Compressive Strength, SC_x : 41,297 psi
 Compressive Modulus, E_x : 3,298,967 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.274

Measured/Theoretical Specimen Dimensions:

Width, W: 1.450 (1.50) in
 Thickness, H: 1.010 (1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Shear
 20% Max Load: 29,403 lbs
 50% Max Load: 11,761 lbs

PICTURE OF SPECIMEN PRE-TEST



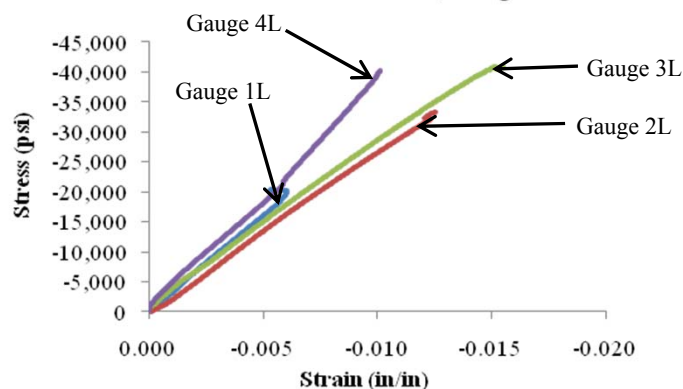
PICTURE OF SPECIMEN POST-TEST



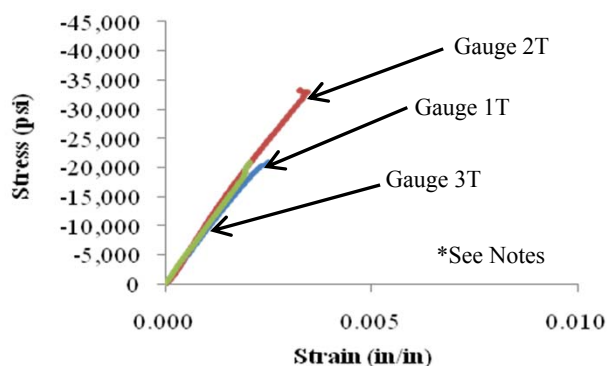
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0077 | -0.0032 | 2,760,120 | 1T | 0.0025 | 0.0009 | -0.4249 |
| 2L | -0.0074 | -0.0030 | 2,819,112 | 2T | 0.0020 | 0.0008 | -0.3302 |
| 3L | -0.0057 | -0.0020 | 3,296,682 | 3T | 0.0020 | 0.0008 | -0.5825 |
| 4L | -0.0054 | -0.0025 | 4,319,954 | Average | | | -0.4457 |
| Average | | | 3,298,967 | | | | |

Stress-Strain Curve 5A, Long.



Stress-Strain Curve 5A, Lat.



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Three lateral gages will not be used for further testing. Information regarding strain gage location missing.

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-CX-140
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: 140°F
 Properties Measured: SC_x , E_x , ν_{xy}

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 48,172 | lbs |
| Compressive Strength, SC_x : | 31,378 | psi |
| Compressive Modulus, E_x : | 2,942,843 | psi |
| Ultimate Strain, ϵ_x : | 0.011 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.367 | |

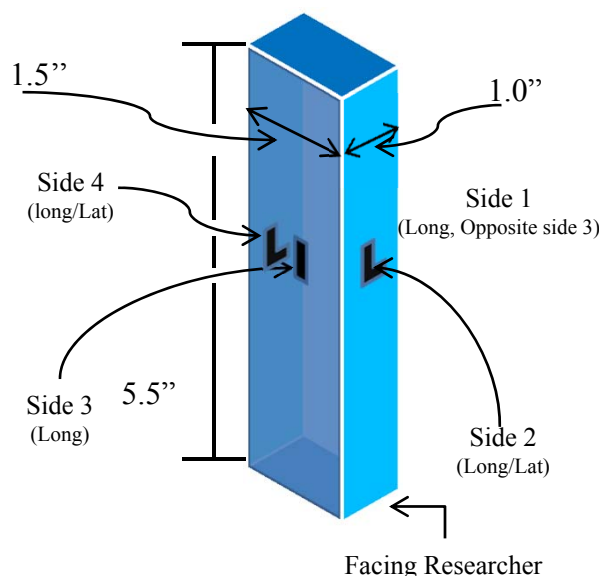
| Sample | Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|---------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MATA-CX-1-140 | 51,125 | 34,898 | 3,170,855 | 0.011 | 0.316 | Delam |
| 2 | MATA-CX-3-140 | 48,201 | 31,158 | 2,713,453 | 0.012 | 0.341 | Delam |
| 3 | MATA-CX-4-140 | 46,845 | 29,518 | 3,060,618 | 0.010 | 0.457 | Delam |
| 4 | MATA-CX-5-140 | 44,153 | 29,633 | 2,903,999 | 0.010 | 0.367 | Delam |
| 5 | MATA-CX-6-140 | 50,536 | 31,684 | 2,865,290 | 0.011 | 0.355 | Delam |
| Average | | 48,172 | 31,378 | 2,942,843 | 0.011 | 0.367 | |

Test Description:

The In-Plane Compression Test performed in accordance with ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

140°F Test Condition**Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) See A-32 to A-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

Specimen Dimensions, Strain Gauges

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-1-140**

Test Date: 2/14/2011

Specimen Received: 11/19/2010

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 51,125 | lbs |
| Compressive Strength, SC_x : | 34,898 | psi |
| Compressive Modulus, E_x : | 3,170,855 | psi |
| Ultimate Strain, ϵ_x : | 0.011 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.316 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|--------------|-----|
| Width, W: | 1.48(1.50) | in |
| Thickness, H: | 0.99(1.00) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Delamination | |
| 20% Max Load | 10,225 | lbs |
| 50% Max Load: | 25,562 | lbs |

PICTURE OF SPECIMEN PRE-TEST



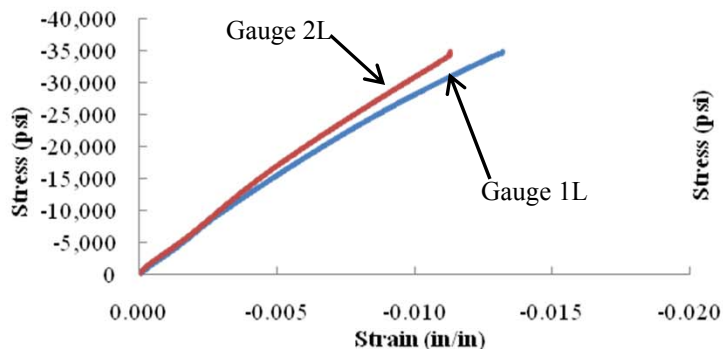
PICTURE OF SPECIMEN POST-TEST



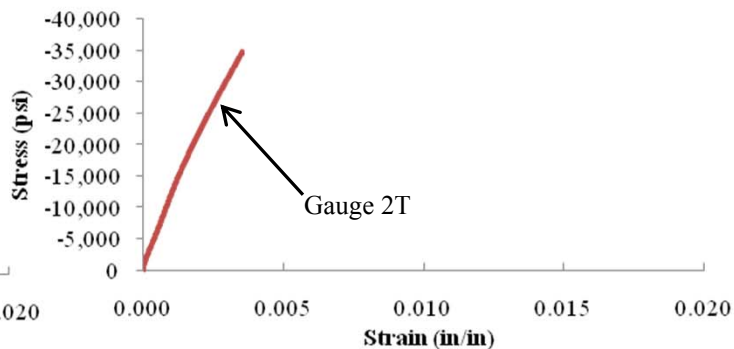
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0057 | -0.0021 | 2,937,487 | 2T | 0.0015 | 0.0006 | 0.316 |
| 2L | -0.0052 | -0.0021 | 3,404,223 | 4T | Lost Gauge | Lost Gauge | Lost Gauge |
| 3L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| 4L | Lost Gauge | Lost Gauge | Lost Gauge | | | | |
| Average | | | 3,170,855 | | | | 0.316 |

Stress-Strain Curve 140_1,Long



Stress-Strain Curve 140_1,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-3-140**

Test Date: 2/15/2011

Specimen Received: 11/5/2010

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 48,201 | lbs |
| Compressive Strength, SC_x : | 31,158 | psi |
| Compressive Modulus, E_x : | 2,713,453 | psi |
| Ultimate Strain, ϵ_x : | 0.012 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.341 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|--------------|-----|
| Width, W: | 1.56(1.50) | in |
| Thickness, H: | 1.00(1.00) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Delamination | |
| 20% Max Load | 9,640 | lbs |
| 50% Max Load: | 24,101 | lbs |

PICTURE OF SPECIMEN PRE-TEST



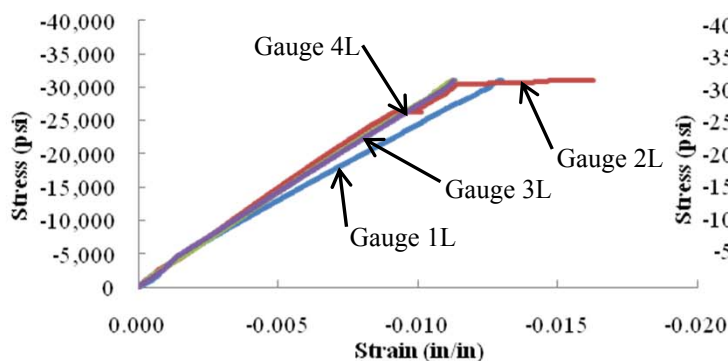
PICTURE OF SPECIMEN POST-TEST



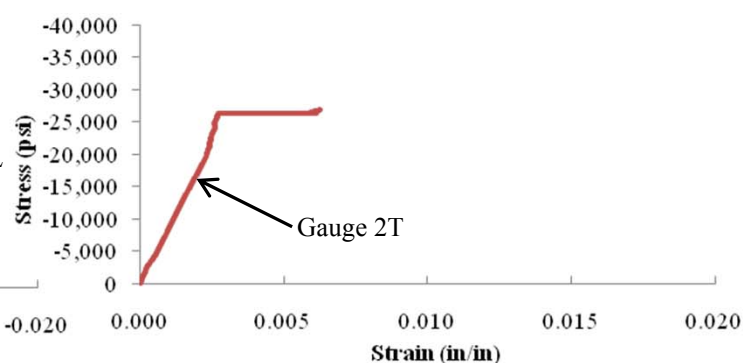
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0061 | -0.0022 | 2,369,132 | 2T | 0.0018 | 0.0008 | 0.341 |
| 2L | -0.0052 | -0.0021 | 3,000,440 | 4T | Lost Gauge | Lost Gauge | - |
| 3L | -0.0055 | -0.0022 | 2,818,048 | | | | |
| 4L | -0.0055 | -0.0020 | 2,666,194 | | | | |
| Average | | | 2,713,453 | | | | 0.341 |

Stress-Strain Curve 140_3,Long



Stress-Strain Curve 140_3,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-4-140**
 Test Date: 2/15/2011
 Specimen Received: 11/5/2010
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 46,845 lbs
 Compressive Strength, SC_x : 29,815 psi
 Compressive Modulus, E_x : 3,1060,618 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.457

Measured/Nominal Specimen Dimensions:

Width, W: 1.56(1.50) in
 Thickness, H: 1.02(1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load 9,369 lbs
 50% Max Load: 23,423 lbs

PICTURE OF SPECIMEN PRE-TEST



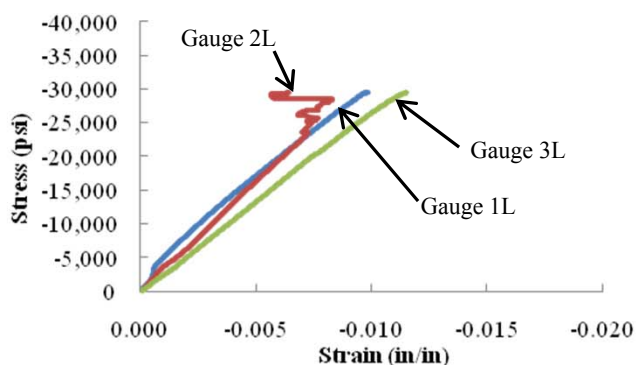
PICTURE OF SPECIMEN POST-TEST



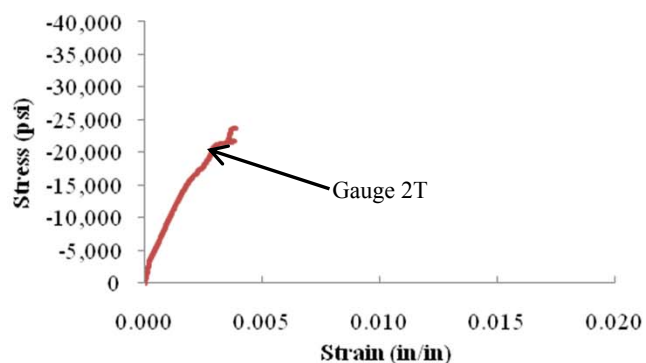
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0041 | -0.0013 | 3,067,940 | 2T | 0.0018 | 0.0005 | 0.457 |
| 2L | -0.0045 | -0.0019 | 3,364,360 | 4T | Lost Gauge | Lost Gauge | - |
| 3L | -0.0056 | -0.0023 | 2,749,553 | | | | |
| 4L | Lost Gauge | Lost Gauge | - | | | | |
| Average | | | 3,060,618 | | | | 0.457 |

Stress-Strain Curve 140_4,Long



Stress-Strain Curve 140_4,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-5-140**
 Test Date: 2/16/2011
 Specimen Received: 11/19/2010
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 44,153 lbs
 Compressive Strength, SC_x : 29,633 psi
 Compressive Modulus, E_x : 2,903,999 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.367

Measured/Nominal Specimen Dimensions:

Width, W: 1.54(1.50) in
 Thickness, H: 0.97(1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 8,831 lbs
 50% Max Load: 22,076 lbs

PICTURE OF SPECIMEN PRE-TEST



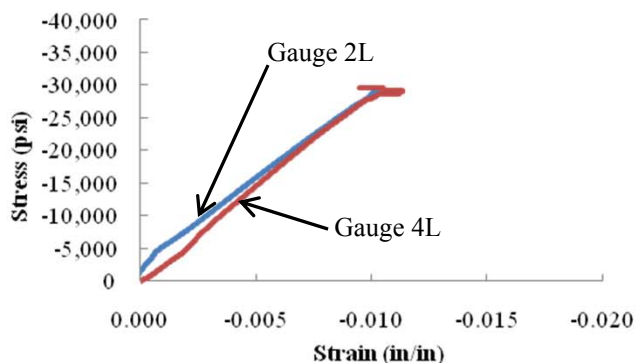
PICTURE OF SPECIMEN POST-TEST



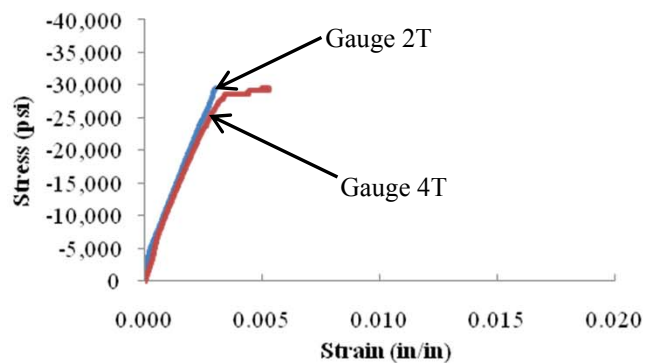
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | 2T | 0.0013 | 0.0003 | 0.394 |
| 2L | -0.0046 | -0.0013 | 2,642,485 | 4T | 0.0014 | 0.0005 | 0.340 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.0051 | -0.0023 | 3,165,513 | | | | |
| Average | | | 2,903,999 | | | | 0.367 |

Stress-Strain Curve 140_5,Long



Stress-Strain Curve 140_5,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MATA-CX-6-140**
 Test Date: 2/16/11
 Specimen Received: 11/19/10
 Properties Measured: SC_x , E_x , ν_{xy}

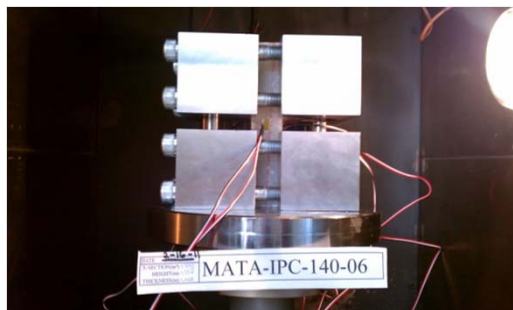
Average Material Properties:

Ultimate Load, P_x : 50,536 lbs
 Compressive Strength, SC_x : 31,684 psi
 Compressive Modulus, E_x : 2,865,290 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.355

Measured/Nominal Specimen Dimensions:

Width, W : 1.55(1.50) in
 Thickness, H : 1.03(1.00) in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 10,107 lbs
 50% Max Load: 25,268 lbs

PICTURE OF SPECIMEN PRE-TEST



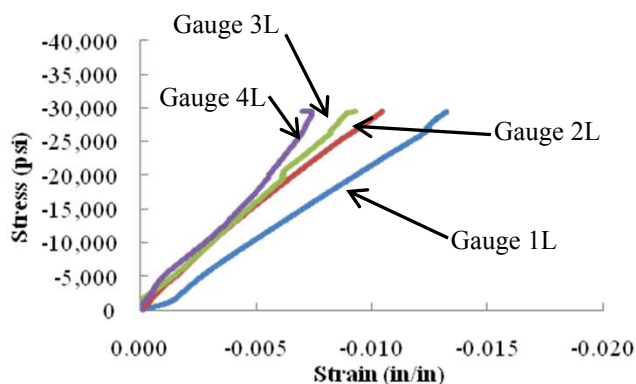
PICTURE OF SPECIMEN POST-TEST



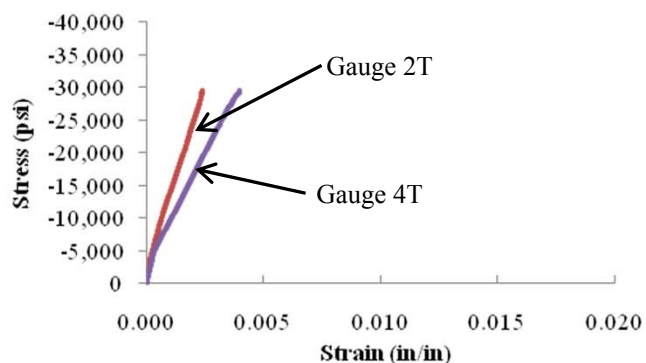
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0074 | -0.0032 | 2,258,853 | 2T | 0.0012 | 0.0004 | 0.266 |
| 2L | -0.0051 | -0.0020 | 3,038,716 | 4T | 0.0019 | 0.0005 | 0.444 |
| 3L | -0.0049 | -0.0019 | 3,101,760 | | | | |
| 4L | -0.0045 | -0.0014 | 3,061,831 | | | | |
| Average | | | 2,865,290 | | | | 0.355 |

Stress-Strain Curve 140_6,Long



Stress-Strain Curve 140_6,Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

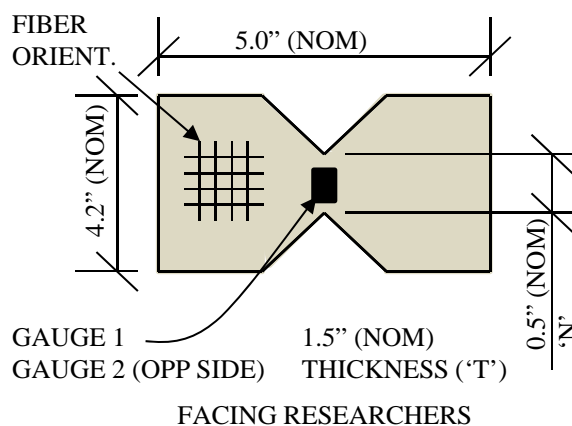
Specimen ID Group: **MATA-SXY-N40**
 Material: **Huntsman Epoxy Resin 8605, DHF**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xy} , S_{xy}**

| | | |
|---------------------------|-----------|-----|
| Maximum Load, P_x : | 28,782 | lbs |
| Shear Stress, S_{xy} : | 32,255 | psi |
| Shear Modulus, G_{xy} : | 1,751,870 | psi |

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|-----------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MATA-SXY-N40-01 | 26,928 | 20,161 | 1,172,867 | Shear |
| 2 | MATA-SXY-N40-02 | 28,311 | 35,805 | 1,846,191 | Shear |
| 3 | MATA-SXY-N40-03 | 29,516 | 33,907 | 1,804,796 | Shear |
| 4 | MATA-SXY-N40-04 | 29,860 | 36,299 | 1,928,690 | Shear |
| 5 | MATA-SXY-N40-05 | 29,296 | 35,106 | 2,006,813 | Shear |
| Average | | 28,782 | 32,255 | 1,751,870 | |

Test Description:

The V-Notch Rail Shear Test per ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grain is oriented in the 'x' and 'y' direction at zero and ninety degrees. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. Actuators apply the load to one fixture half which introduces a shear through the specimen. The shear stress is maximized at the notch. A rate of 0.05 in/min is used.

-40°F Test Condition**Specimens Dimensions, Strain Gages****Notes:**

- 1) Individual specimen results are shown on Sheets A-38 to A-42

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-N40-01
 Test Date: 1/12/11
 Specimen Rcvd.: 1/7/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 26,928 lbs
 Shear Stress, S_{xy} : 20,161 psi
 Shear Modulus, G_{xy} : 1,172,867 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.47 (1.50) in
 Notch Length, N: 0.51 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,386 lbs
 50% Max Load: 13,464 lbs

PICTURE OF SPECIMEN PRE-TEST



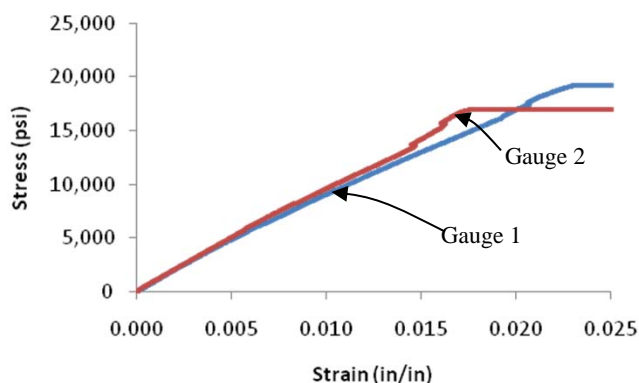
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.01129 | 0.00411 | 1,124,545 |
| 2 | 0.01057 | 0.00396 | 1,221,189 |
| Average | | | 1,172,867 |

Stress-Strain Curve 1A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges(one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: **MATA-SXY-N40-02**
 Test Date: 1/12/11
 Specimen Rcvd.: 1/7/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 28,311 lbs
 Shear Stress, S_{xy} : 35,805 psi
 Shear Modulus, G_{xy} : 1,846,191 psi

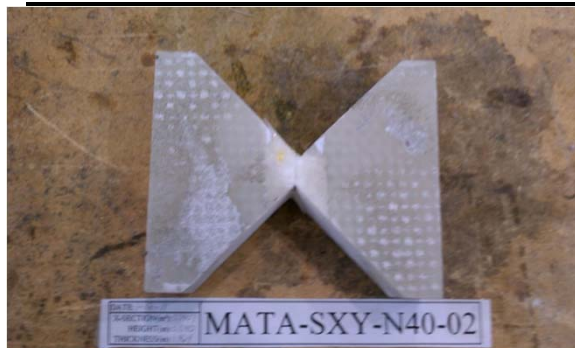
Measured/Theoretical Specimen Dimensions:

Thickness, T : 1.46 (1.50) in
 Notch Length, N : 0.54 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,662 lbs
 50% Max Load: 14,156 lbs

PICTURE OF SPECIMEN PRE-TEST



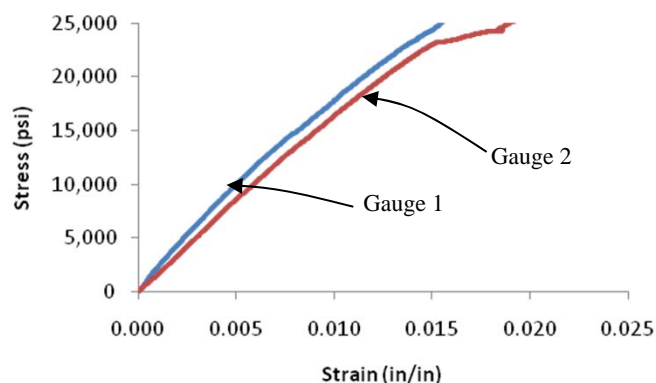
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.01012 | 0.00347 | 2,048,725 |
| 2 | 0.01111 | 0.00280 | 1,643,657 |
| Average | | | 1,846,191 |

Stress-Strain Curve 2A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-N40-03
 Test Date: 1/13/11
 Specimen Rcvd.: 1/7/11
 Properties Measured: S_{xy} , G_{xy}

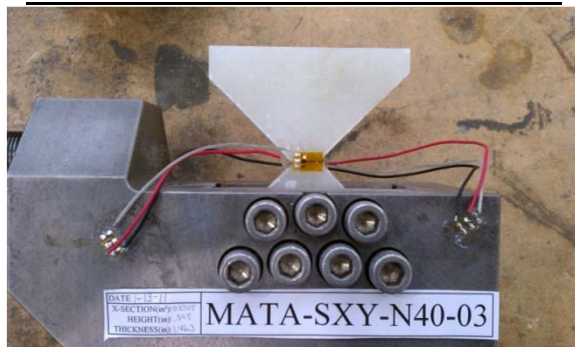
Average Material Properties:

Ultimate Load, P_{max} : 29,516 lbs
 Shear Stress, S_{xy} : 33,907 psi
 Shear Modulus, G_{xy} : 1,804,796 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.46 (1.50) in
 Notch Length, N: 0.60 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,903 lbs
 50% Max Load: 14,758 lbs

PICTURE OF SPECIMEN PRE-TEST



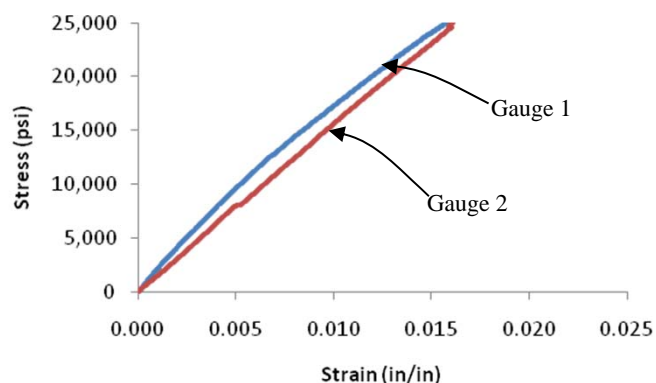
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.00977 | 0.00343 | 1,844,936 |
| 2 | 0.01085 | 0.00422 | 1,764,655 |
| Average | | | 1,804,796 |

Stress-Strain Curve 3A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: **MATA-SXY-N40-04**
 Test Date: 1/13/11
 Specimen Rcvd.: 1/7/11
 Properties Measured: S_{xy} , G_{xy}

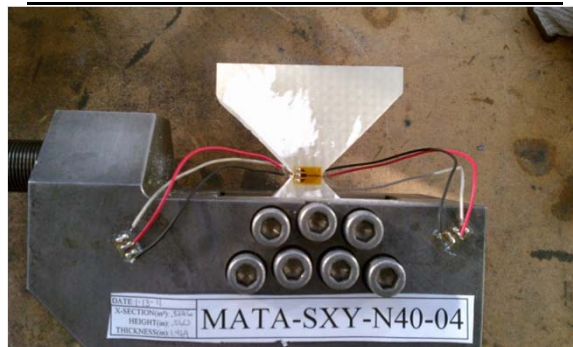
Average Material Properties:

Ultimate Load, P_{max} : 29,860 lbs
 Shear Stress, S_{xy} : 36,299 psi
 Shear Modulus, G_{xy} : 1,928,690 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.47 (1.50) in
 Notch Length, N: 0.56 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,972 lbs
 50% Max Load: 14,930 lbs

PICTURE OF SPECIMEN PRE-TEST



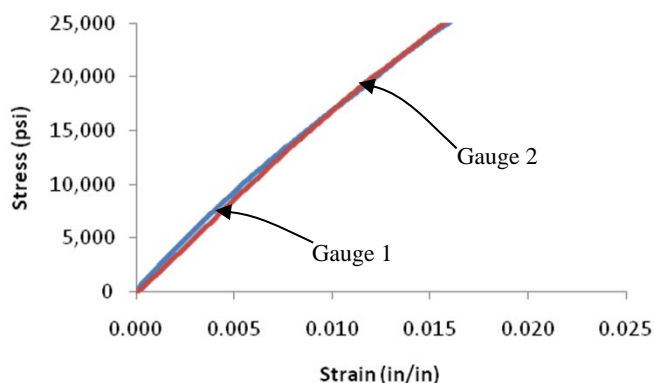
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.01096 | 0.00380 | 1,851,501 |
| 2 | 0.01083 | 0.00423 | 2,005,879 |
| Average | | | 1,928,690 |

Stress-Strain Curve 4A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-N40-05
 Test Date: 1/13/11
 Specimen Rcvd.: 1/7/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 29,296 lbs
 Shear Stress, S_{xy} : 35,106 psi
 Shear Modulus, G_{xy} : 2,006,813 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.46 (1.50) in
 Notch Length, N: 0.57 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,589 lbs
 50% Max Load: 14,648 lbs

PICTURE OF SPECIMEN PRE-TEST



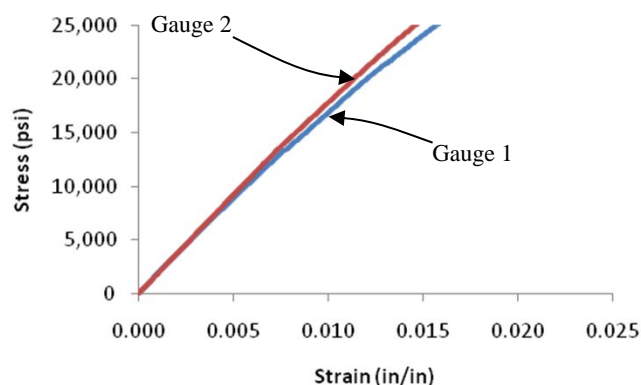
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.01047 | 0.00390 | 1,924,177 |
| 2 | 0.00986 | 0.00381 | 2,089,449 |
| Average | | | 2,006,813 |

Stress-Strain Curve 5A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

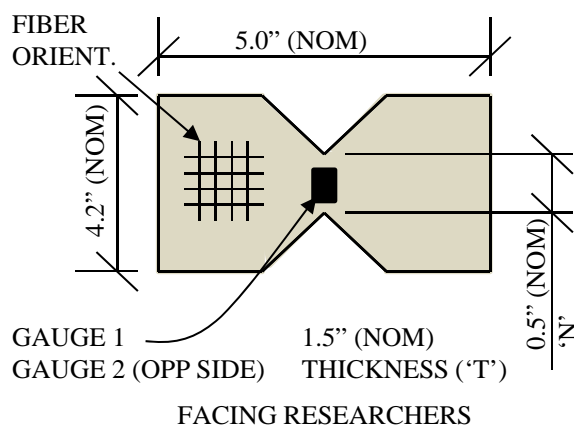
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MATA-SXY-70**
 Material: **Huntsman Epoxy Resin 8605, DHF**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : **23,971** **lbs**
 Shear Stress, S_{xy} : **25,929** **psi**
 Shear Modulus, G_{xy} : **1,375,199** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MATA-SXY-1-70 | 23,463 | 20,334 | 1,427,092 | Shear |
| 2 | MATA-SXY-2-70 | 22,467 | 24,997 | 1,501,127 | Shear |
| 3 | MATA-SXY-3-70 | 23,694 | 28,897 | 1,500,009 | Shear |
| 4 | MATA-SXY-4-70 | 27,030 | 28,244 | 1,222,450 | Shear |
| 5 | MATA-SXY-5-70 | 23,201 | 27,173 | 1,225,217 | Shear |
| Average | | 23,971 | 25,929 | 1,375,199 | |

Test Description:

The V-Notch Rail Shear Test per ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grain is oriented in the 'x' and 'y' direction at zero and ninety degrees. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. Actuators apply the load to one fixture half which introduces a shear through the specimen. The shear stress is maximized at the notch. A rate of 0.05 in/min is used.

Ambient Temp. Test Cond.**Specimens Dimensions, Strain Gages****Notes:**

- 1) Individual specimen results are shown on Sheets A-44 to A-48
- 2) Original fixture shown in picture above.

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-1-70
 Test Date: 9/10/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: S_{xy} , G_{xy}

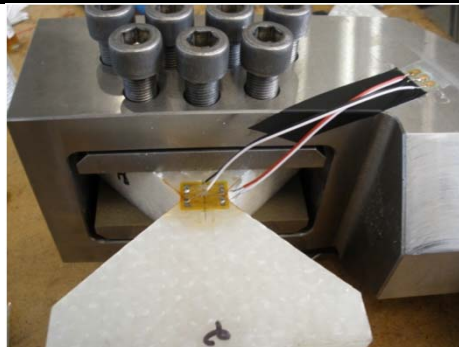
Average Material Properties:

Ultimate Load, P_{max} : 23,463 lbs
 Shear Stress, S_{xy} : 20,334 psi
 Shear Modulus, G_{xy} : 1,427,092 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.48 (1.50) in
 Notch Length, N: 0.58 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,693 lbs
 50% Max Load: 11,731 lbs

PICTURE OF SPECIMEN PRE-TEST



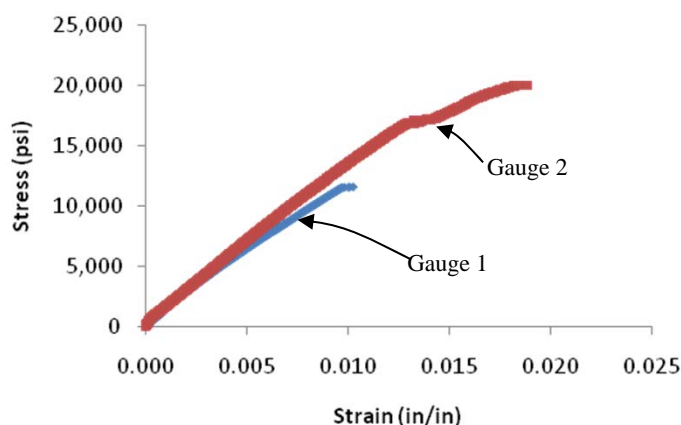
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0083 | 0.0029 | 1,305,775 |
| 2 | 0.0073 | 0.0027 | 1,548,409 |
| Average | | | 1,427,192 |

Stress-Strain Curve 1A



Engineering Test notes:

- *Specimen was fitted with two Vishay 250TK strain gauges(one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: **MATA-SXY-2-70**
 Test Date: 8/30/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 22,467 lbs
 Shear Stress, S_{xy} : 24,997 psi
 Shear Modulus, G_{xy} : 1,501,127 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.50 (1.50) in
 Notch Length, N: 0.60 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,493 lbs
 50% Max Load: 11,233 lbs

PICTURE OF SPECIMEN PRE-TEST



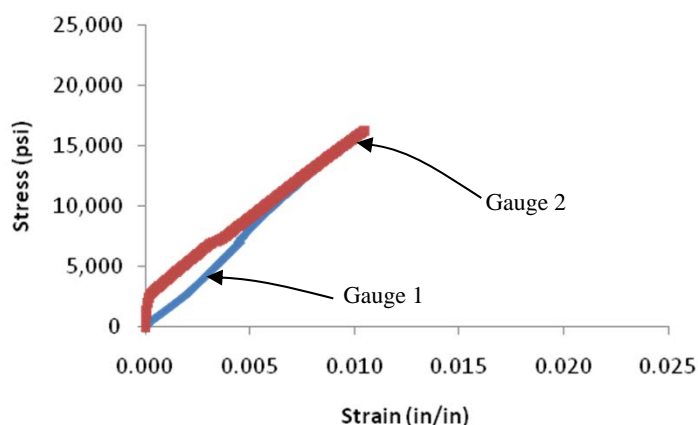
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0077 | 0.0033 | 1,705,505 |
| 2 | 0.0075 | 0.0018 | 1,296,748 |
| Average | | | 1,501,127 |

Stress-Strain Curve 2A



Engineering Test notes:

- *Specimen was fitted with two 187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-3-70
 Test Date: 9/8/2010
 Specimen Rcvd.: 8/5/2010
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 23,694 lbs
 Shear Stress, S_{xy} : 28,897 psi
 Shear Modulus, G_{xy} : 1,500,009 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.48 (1.50) in
 Notch Length, N: 0.55 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,739 lbs
 50% Max Load: 11,847 lbs

PICTURE OF SPECIMEN PRE-TEST



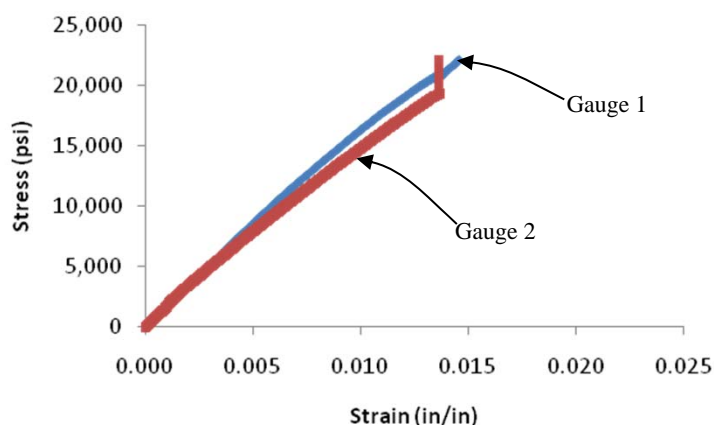
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0087 | 0.0033 | 1,602,628 |
| 2 | 0.0098 | 0.0036 | 1,397,388 |
| Average | | | 1,500,009 |

Stress-Strain Curve 3A



Engineering Test notes:

- *Specimen was fitted with two Vishay 187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: **MATA-SXY-4-70**
 Test Date: 10/1/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: S_{xy} , G_{xy}

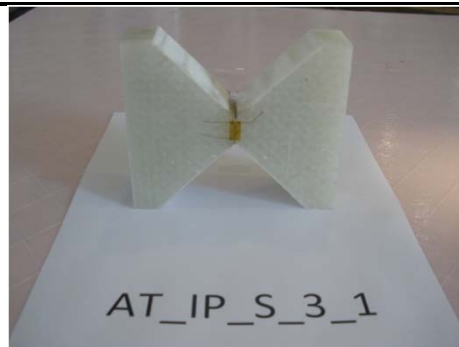
Average Material Properties:

Ultimate Load, P_{max} : 27,030 lbs
 Shear Stress, S_{xy} : 28,244 psi
 Shear Modulus, G_{xy} : 1,222,450 psi

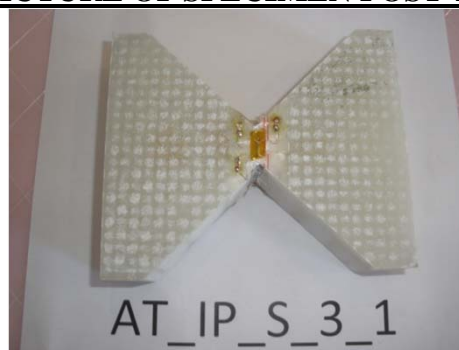
Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.45 (1.50) in
 Notch Length, N: 0.66 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,406 lbs
 50% Max Load: 13,515 lbs

PICTURE OF SPECIMEN PRE-TEST



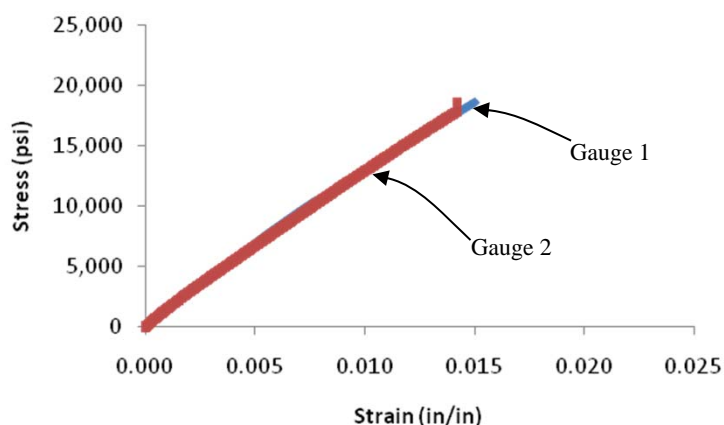
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Iosipescu Strain Gauges | | | |
|-------------------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0110 | 0.0040 | 1,210,981 |
| 2 | 0.0110 | 0.0042 | 1,233,918 |
| Average | | | 1,222,450 |

Stress-Strain Curve 4A



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: **MATA-SXY-5-70**
 Test Date: 10/7/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 23,201 lbs
 Shear Stress, S_{xy} : 27,173 psi
 Shear Modulus, G_{xy} : 1,225,217 psi

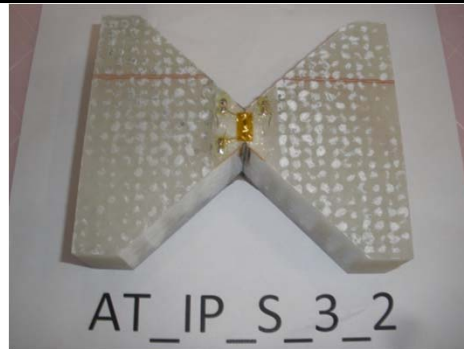
Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.44 (1.50) in
 Notch Length, N: 0.60 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,640 lbs
 50% Max Load: 11,601 lbs

PICTURE OF SPECIMEN PRE-TEST



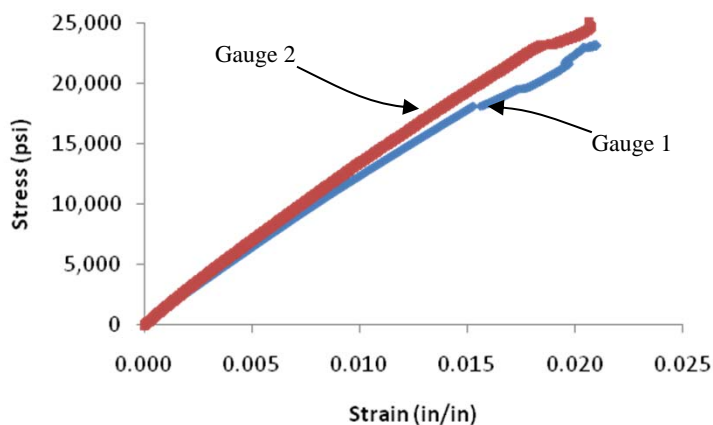
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Iosipescu Strain Gauges | | | |
|-------------------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 11 | 0.0111 | 0.0041 | 1,170,565 |
| 21 | 0.0102 | 0.0038 | 1,279,869 |
| Average | | | 1,225,217 |

Stress-Strain Curve 5A



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

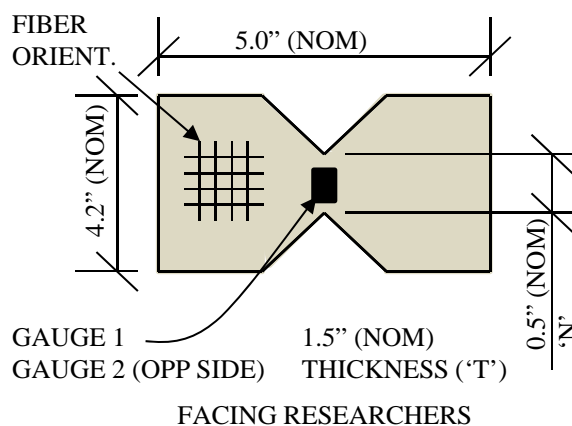
Specimen ID Group: MATA-SXY-140
Material: Huntsman Epoxy Resin 8605, DHF
Nominal Temperature: 140°F
Properties Measured: G_{xy} , S_{xy}
Average Material Properties (5 Specimens):

| | | |
|---------------------------|-----------|-----|
| Maximum Load, P_x : | 23,122 | lbs |
| Shear Stress, S_{xy} : | 24,338 | psi |
| Shear Modulus, G_{xy} : | 1,351,465 | psi |

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|-----------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MATA-SXY-140-01 | 22,215 | 23,594 | 1,392,044 | Shear |
| 2 | MATA-SXY-140-02 | 23,993 | 25,256 | 1,355,596 | Shear |
| 3 | MATA-SXY-140-03 | 23,358 | 24,587 | 1,329,585 | Shear |
| 4 | MATA-SXY-140-04 | 22,772 | 23,971 | 1,354,755 | Shear |
| 5 | MATA-SXY-140-05 | 23,069 | 24,283 | 1,325,345 | Shear |
| Average | | 23,122 | 24,338 | 1,351,465 | |

Test Description:

The V-Notch Rail Shear Test per ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grain is oriented in the 'x' and 'y' direction at zero and ninety degrees. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. Actuators apply the load to one fixture half which introduces a shear through the specimen. The shear stress is maximized at the notch. A rate of 0.05 in/min is used.

140°F Test Condition**Specimens Dimensions, Strain Gages****Notes:**

- 1) Individual specimen results are shown on Sheets A-50 to A-54

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-140-01
 Test Date: 1/6/11
 Specimen Rcvd.: 11/19/10
 Properties Measured: S_{xy} , G_{xy}

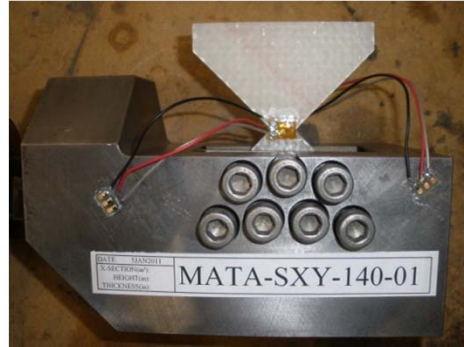
Average Material Properties:

Ultimate Load, P_{max} : 22,415 lbs
 Shear Stress, S_{xy} : 24,258 psi
 Shear Modulus, G_{xy} : 1,431,214 psi

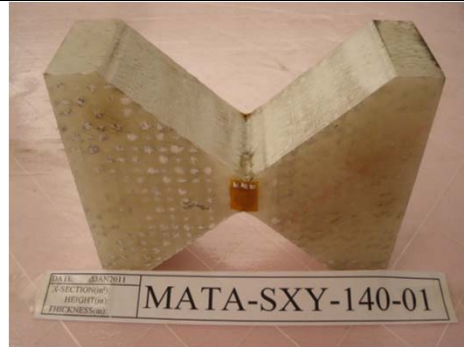
Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.52 (1.50) in
 Notch Length, N: 0.50 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,483 lbs
 50% Max Load: 11,207 lbs

PICTURE OF SPECIMEN PRE-TEST



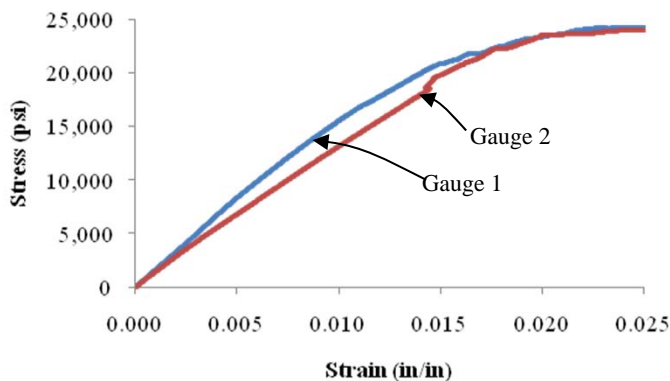
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0075 | 0.0029 | 1,589,159 |
| 2 | 0.0092 | 0.0034 | 1,273,269 |
| Average | | | 1,431,214 |

Stress-Strain Curve 1A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges(one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-140-02
 Test Date: 1/6/11
 Specimen Rcvd.: 11/19/10
 Properties Measured: S_{xy} , G_{xy}

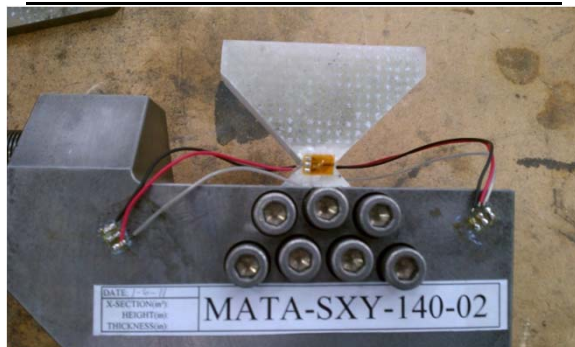
Average Material Properties:

Ultimate Load, P_{max} : 23,993 lbs
 Shear Stress, S_{xy} : 26,137 psi
 Shear Modulus, G_{xy} : 1,402,850 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.52 (1.50) in
 Notch Length, N: 0.50 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,799 lbs
 50% Max Load: 11,997 lbs

PICTURE OF SPECIMEN PRE-TEST



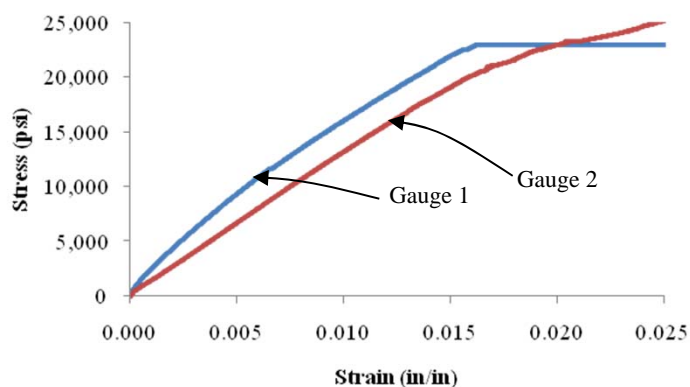
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0077 | 0.0025 | 1,502,586 |
| 2 | 0.0099 | 0.0039 | 1,303,114 |
| Average | | | 1,402,850 |

Stress-Strain Curve 2A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-140-03
 Test Date: 1/7/11
 Specimen Rcvd.: 11/19/10
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 23,358 lbs
 Shear Stress, S_{xy} : 24,230 psi
 Shear Modulus, G_{xy} : 1,310,275 psi

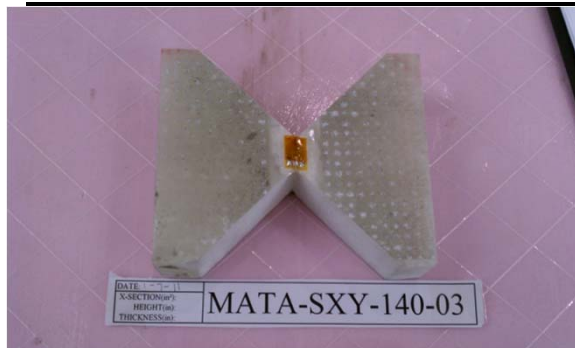
Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.52 (1.50) in
 Notch Length, N: 0.50 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,672 lbs
 50% Max Load: 11,679 lbs

PICTURE OF SPECIMEN PRE-TEST



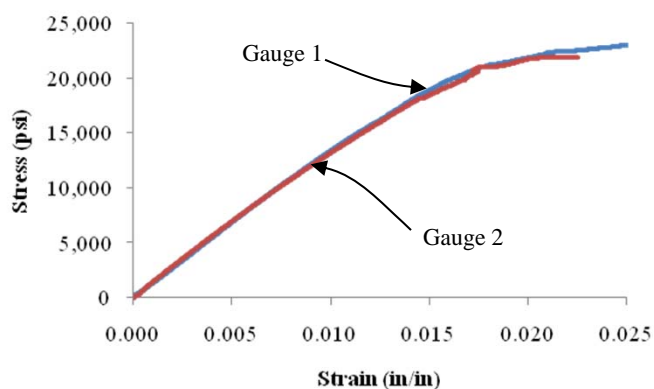
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0090 | 0.0035 | 1,337,401 |
| 2 | 0.0091 | 0.0034 | 1,283,150 |
| Average | | | 1,310,275 |

Stress-Strain Curve 3A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-140-04
 Test Date: 1/7/11
 Specimen Rcvd.: 11/19/10
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 22,772 lbs
 Shear Stress, S_{xy} : 23,332 psi
 Shear Modulus, G_{xy} : 1,318,665 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T: 1.52 (1.50) in
 Notch Length, N: 0.50 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,554 lbs
 50% Max Load: 11,386 lbs

PICTURE OF SPECIMEN PRE-TEST



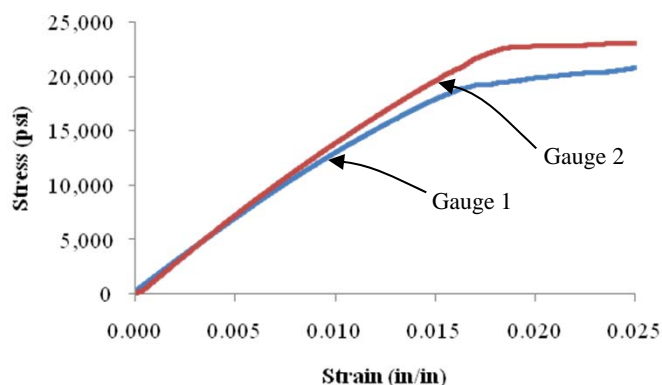
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0088 | 0.0032 | 1,248,759 |
| 2 | 0.0083 | 0.0032 | 1,388,572 |
| Average | | | 1,318,665 |

Stress-Strain Curve 4A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY

Specimen ID: MATA-SXY-140-05
 Test Date: 1/10/11
 Specimen Rcvd.: 11/19/10
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 23,069 lbs
 Shear Stress, S_{xy} : 25,061 psi
 Shear Modulus, G_{xy} : 1,365,594 psi

Measured/Theoretical Specimen Dimensions:

Thickness, T : 1.52 (1.50) in
 Notch Length, N : 0.50 (0.50) in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,614 lbs
 50% Max Load: 11,535 lbs

PICTURE OF SPECIMEN PRE-TEST



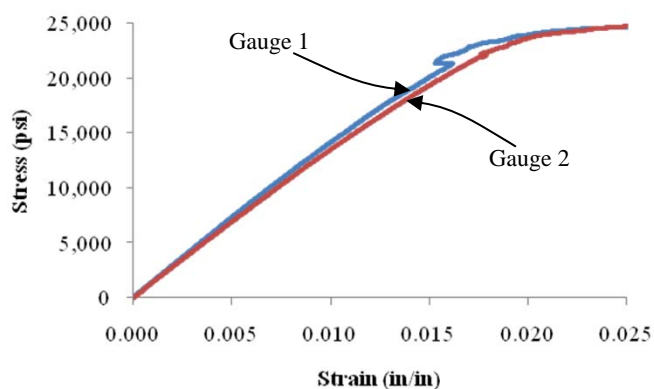
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0088 | 0.0034 | 1,396,864 |
| 2 | 0.0092 | 0.0036 | 1,334,325 |
| Average | | | 1,365,594 |

Stress-Strain Curve 5A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-TZ-N40_ (Spooled Specimens)

Material: Huntsman Epoxy Resin 8605, DHF

Nominal Temperature: -40°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

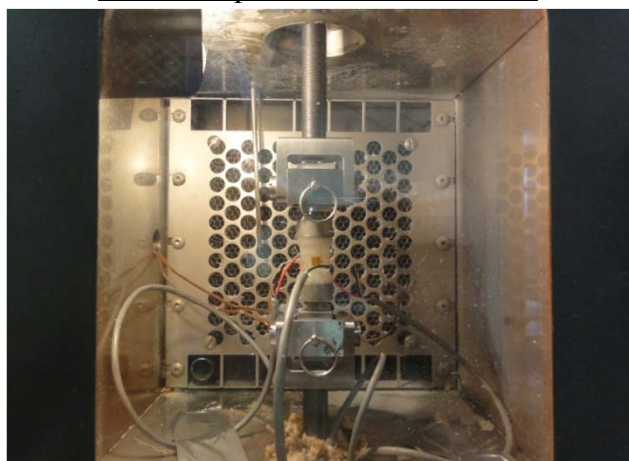
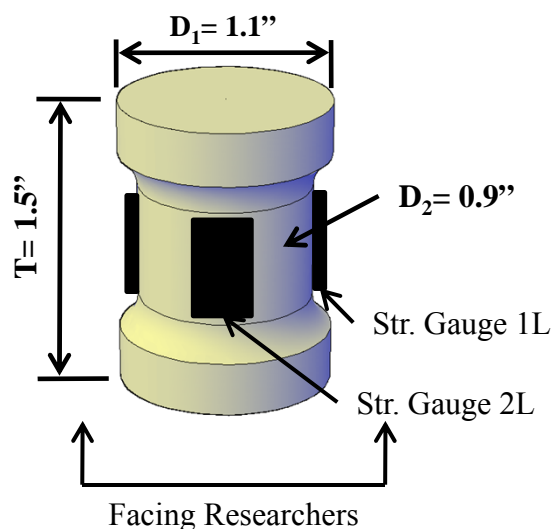
Maximum Stress, ST_z : 2,494 psi

Tensile Modulus, E_z : 1,675,613 psi

| TEST | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|----------------|-----------------------------------|---------------------------------|--------------|
| MATA-TZ-1-N40 | 1,989 | 1,704,773 | Rupture |
| MATA-TZ-2-N40 | 2,813 | 1,712,659 | Rupture |
| MATA-TZ-3-N40 | 2,342 | 1,657,796 | Rupture |
| MATA-TZ-4-N40 | 2,625 | 1,610,755 | Rupture |
| MATA-TZ-5-N40 | 2,704 | 1,692,085 | Rupture |
| Average | 2,494 | 1,675,613 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and elastic modulus of fiber reinforced polymer matrix composite materials. The fiber grain direction is along two axes. There are no fibers directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A tensile force is applied at a rate of 0.005 in/min normal to the plane of the composite laminate using adhesively bonded metal end-tabs. The specimen consists of a 1.1 inch diameter cylinder with a reduced gauge section of 0.9 inch diameter. The test is performed on the Instron 8502A. Three longitudinal strain gages are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow universal tension.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference A-56 to A-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-1-N40**
 Test Date: 3/28/2011
 Specimen Received: 3/17/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,989 psi
 Tensile Modulus, E_z : 1,704,773 psi

Measured Specimen Dimensions:

Length, L: 1.32 in
 Diameter, D_1 : 1.0599 in
 Diameter, D_2 : 0.8599 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture

50% Max Stress: 994 psi
 20% Max Stress: 398 psi

PICTURE OF SPECIMEN PRE-TEST



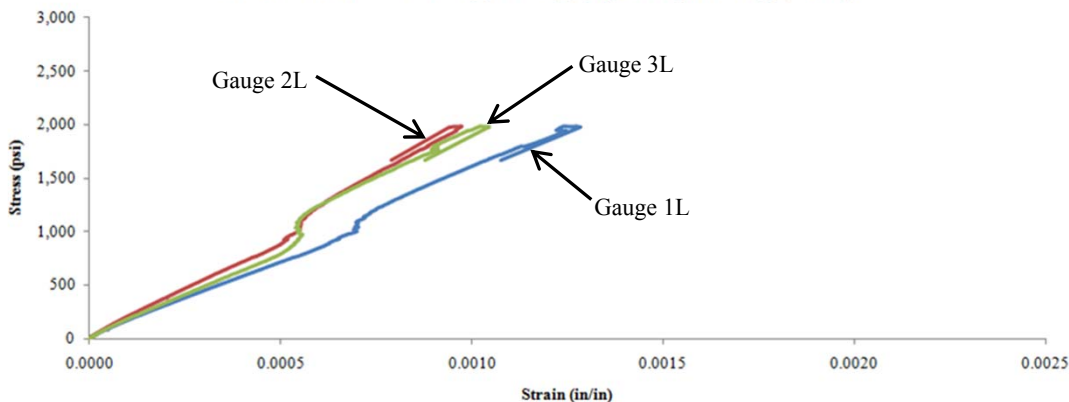
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000688 | 0.000256 | 1,379,051 |
| 2L | 0.000537 | 0.000204 | 1,793,971 |
| 3L | 0.000544 | 0.000237 | 1,941,295 |
| Average | | | 1,704,773 |

Stress-Strain Curve _-40°F_1_(Acceptance)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-2-N40**
 Test Date: 3/30/2011
 Specimen Received: 3/17/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,813 psi
 Tensile Modulus, E_z : 1,712,659 psi

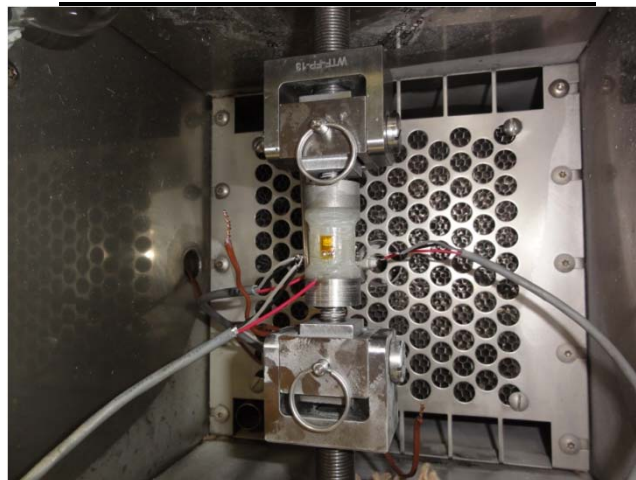
Measured Specimen Dimensions:

Length, L: 1.35 in
 Diameter, D_1 : 1.0634 in
 Diameter, D_2 : 0.8634 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture

50% Max Stress: 1,406 psi
 20% Max Stress: 563 psi

PICTURE OF SPECIMEN PRE-TEST



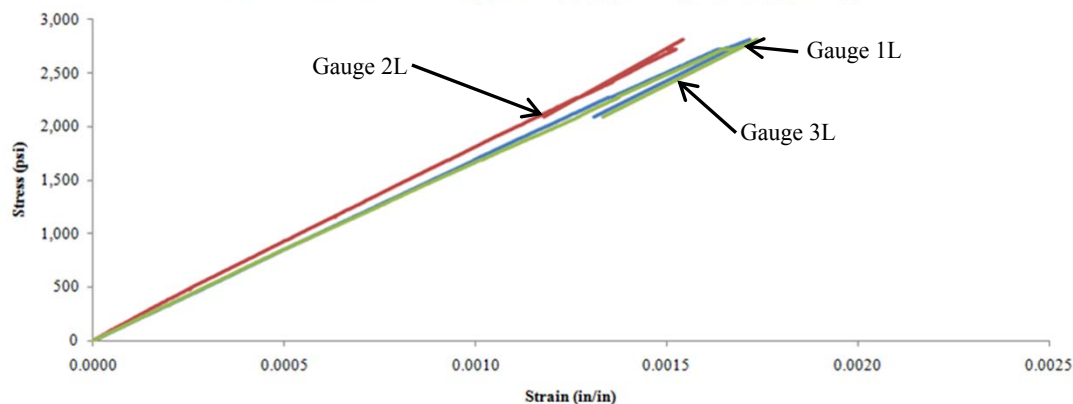
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000827 | 0.000329 | 1,695,139 |
| 2L | 0.000766 | 0.000291 | 1,776,847 |
| 3L | 0.000834 | 0.000328 | 1,665,990 |
| Average | | | 1,712,659 |

Stress-Strain Curve _-40°F_2_(Acceptance)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-3-N40**
 Test Date: 3/30/2011
 Specimen Received: 3/17/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,342 psi
 Tensile Modulus, E_z : 1,657,796 psi

Measured Specimen Dimensions:

Length, L: 1.30 in
 Diameter, D_1 : 1.0922 in
 Diameter, D_2 : 0.8922 in

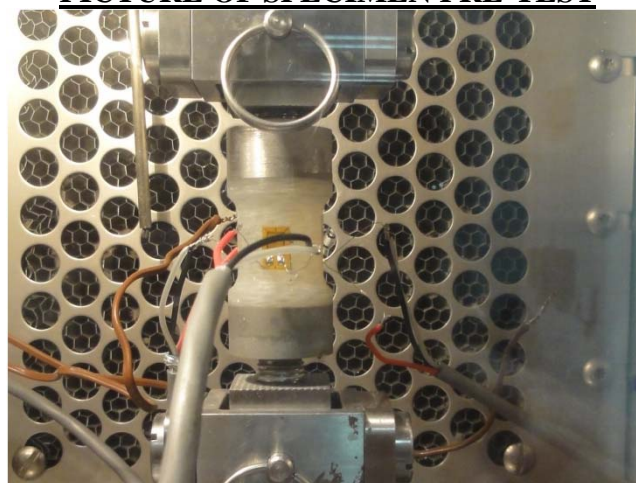
Laboratory Temperature: 68°F

Failure Mode: Rupture

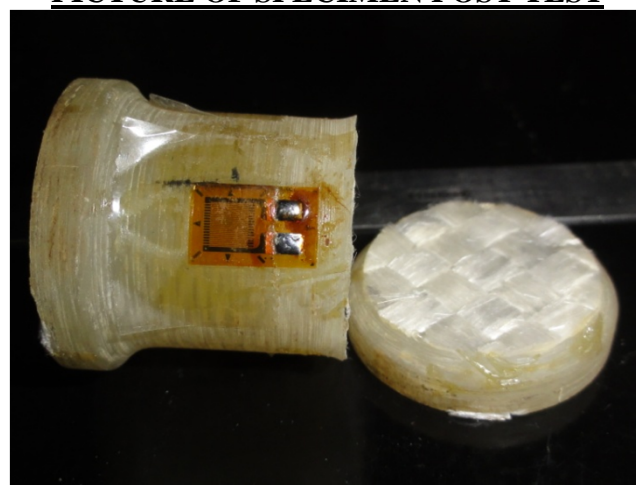
50% Max Stress: 1,171 psi

20% Max Stress: 468 psi

PICTURE OF SPECIMEN PRE-TEST



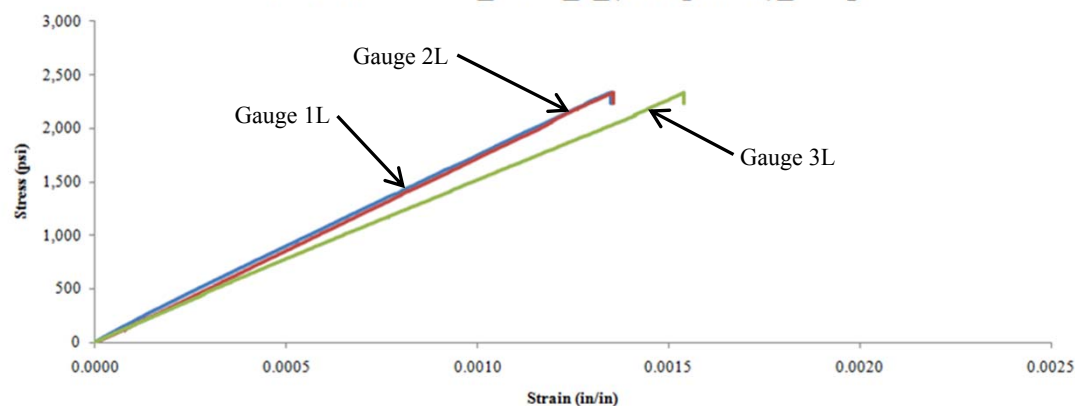
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000654 | 0.000247 | 1,728,349 |
| 2L | 0.000677 | 0.000276 | 1,749,984 |
| 3L | 0.000760 | 0.000290 | 1,495,055 |
| Average | | | 1,657,796 |

Stress-Strain Curve_-40°F_3_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-4-N40**
 Test Date: 4/4/2011
 Specimen Received: 3/17/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,625 psi
 Tensile Modulus, E_z : 1,610,755 psi

Measured Specimen Dimensions:

Length, L: 1.27 in
 Diameter, D_1 : 1.8585 in
 Diameter, D_2 : 0.8585 in

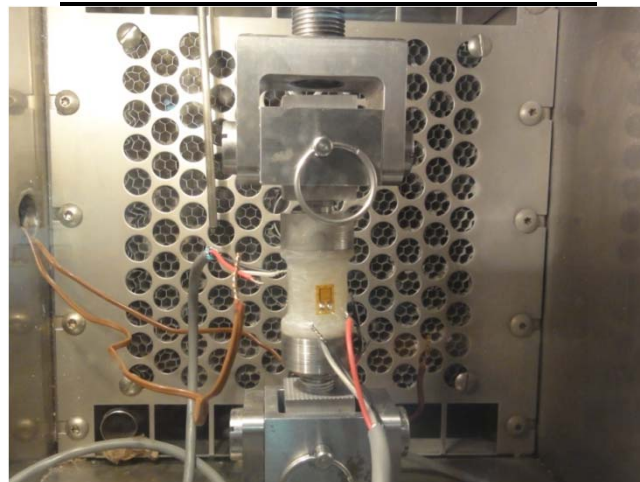
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,313 psi

20% Max Stress: 525 psi

PICTURE OF SPECIMEN PRE-TEST



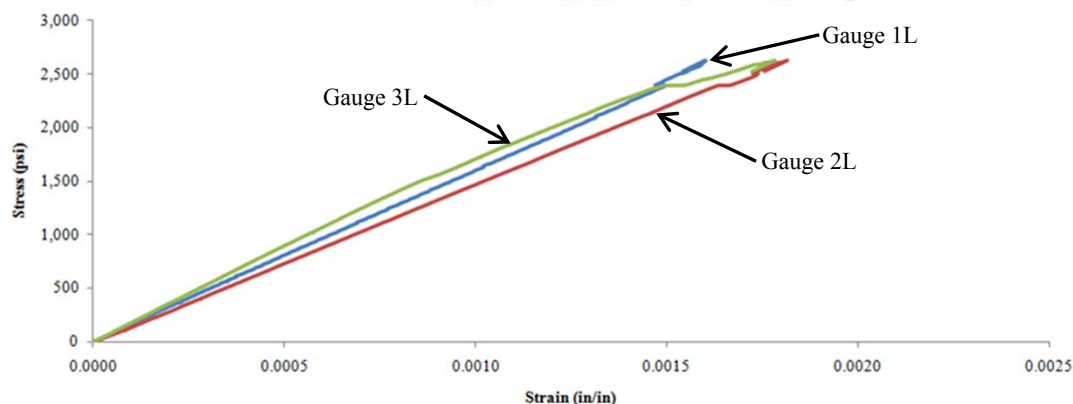
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000818 | 0.000322 | 1,589,074 |
| 2L | 0.000891 | 0.000360 | 1,484,072 |
| 3L | 0.000739 | 0.000291 | 1,759,119 |
| Average | | | 1,610,755 |

Stress-Strain Curve _-40°F_4_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-5-N40**
 Test Date: 4/5/2011
 Specimen Received: 3/17/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,704 psi
 Tensile Modulus, E_z : 1,692,085 psi

Measured Specimen Dimensions:

Length, L: 1.29 in
 Diameter, D_1 : 1.0585 in
 Diameter, D_2 : 0.8585 in

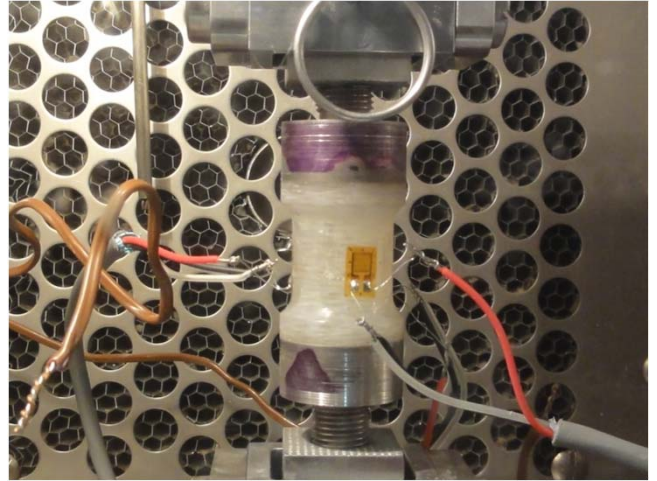
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,352 psi

20% Max Stress: 541 psi

PICTURE OF SPECIMEN PRE-TEST



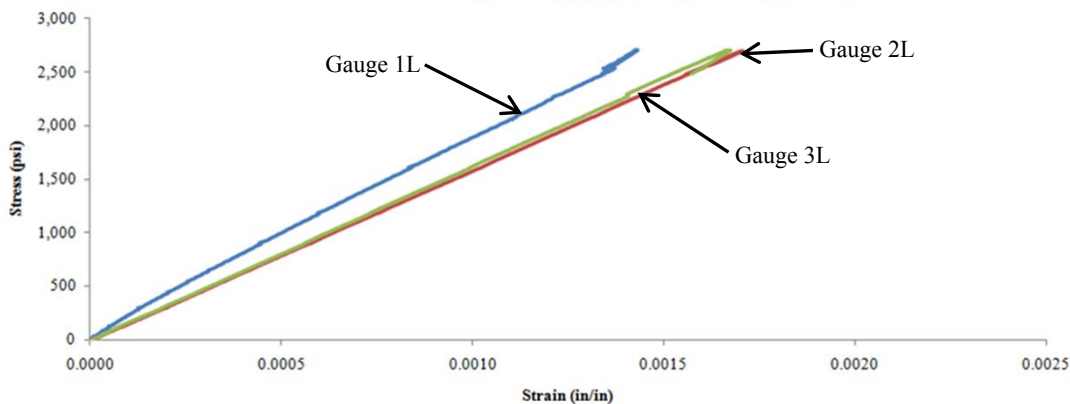
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000693 | 0.000255 | 1,851,351 |
| 2L | 0.000853 | 0.000344 | 1,591,334 |
| 3L | 0.000835 | 0.000338 | 1,633,569 |
| Average | | | 1,692,085 |

Stress-Strain Curve _-40°F_5_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-TZ-70_(Spooled Specimens)

Material: Huntsman Epoxy Resin 8605, DHF

Nominal Temperature: 70°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

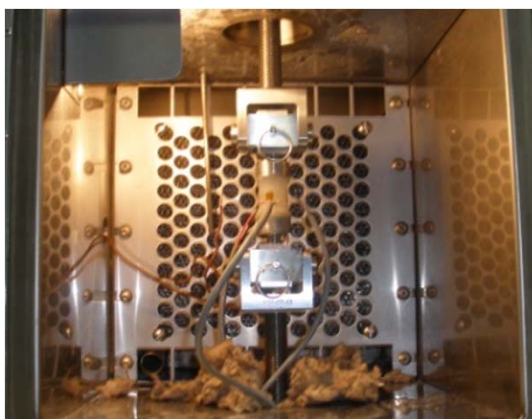
Maximum Stress, ST_z : 2,318 psi

Tensile Modulus, E_z : 1,400,195 psi

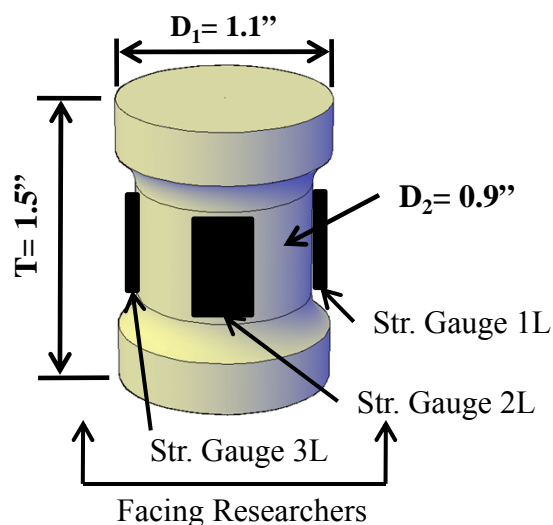
| TEST | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|----------------|-----------------------------------|---------------------------------|--------------|
| MATA-TZ-70-1 | 2,194 | 1,461,872 | Rupture |
| MATA-TZ-70-2 | 2,582 | 1,419,686 | Rupture |
| MATA-TZ-70-3 | 2,203 | 1,390,976 | Rupture |
| MATA-TZ-70-4 | 2,476 | 1,515,977 | Rupture |
| MATA-TZ-70-5 | 2,135 | 1,212,464 | Rupture |
| Average | 2,318 | 1,400,195 | |

Test Description:

The Flat Wise Tensile test within the guidelines of ASTM D7291 measures the through-thickness “flatwise” tensile strength and elastic modulus of fiber reinforced polymer matrix composite materials. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A tensile force is applied at a rate of 0.005 in/min normal to the plane of the composite laminate using adhesively bonded thick metal end-tabs. The specimen consists of a 1.1 inch diameter cylinder with a reduced gauge section of 0.9 inch diameter. The test is performed on the Instron 8502A. Three longitudinal strain gages are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow universal tension.

Ambient Temperature Test Condition**Notes:**

- 1) Reference A-62 to A-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-1-70**
 Test Date: 3/09/2011
 Specimen Received: 1/13/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,194 psi
 Tensile Modulus, E_z : 1,461,872 psi

Measured Specimen Dimensions:

Length, L: 1.5 in
 Diameter, D_1 : 1.1 in
 Diameter, D_2 : 0.9 in

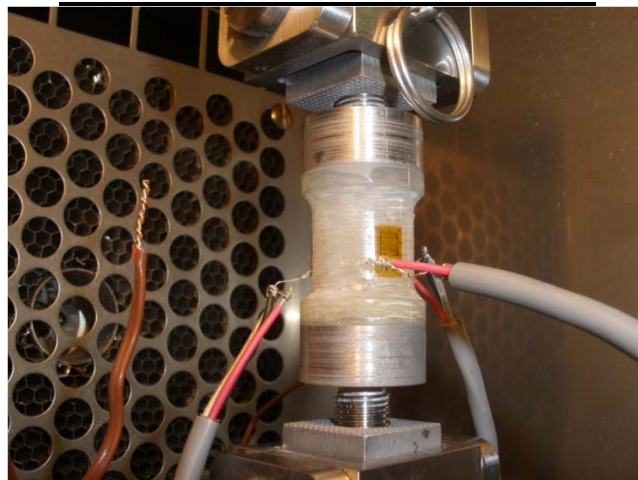
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,097 psi

20% Max Stress: 439 psi

PICTURE OF SPECIMEN PRE-TEST



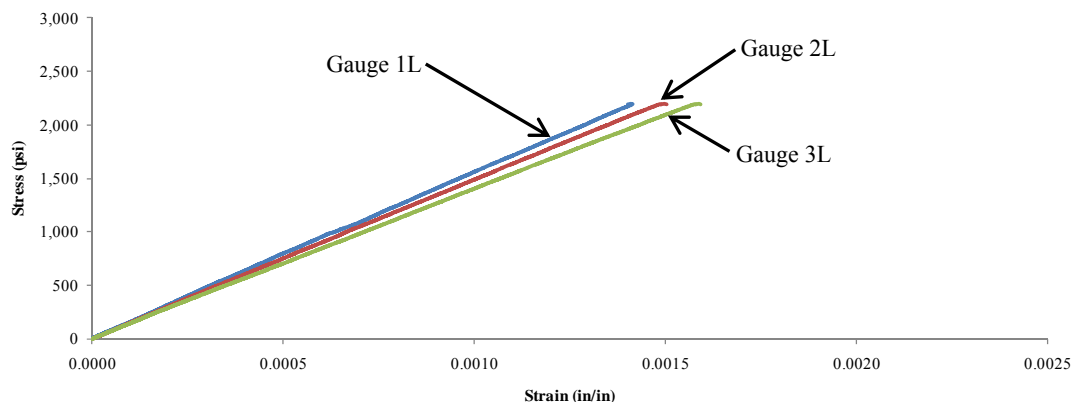
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000704 | 0.000271 | 1,520,316 |
| 2L | 0.000732 | 0.000288 | 1,481,344 |
| 3L | 0.000781 | 0.000305 | 1,383,956 |
| Average | | | 1,461,872 |

Stress-Strain Curve_70°F_1_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-2-70**
 Test Date: 3/22/2011
 Specimen Received: 1/13/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,582 psi
 Tensile Modulus, E_z : 1,419,686 psi

Measured Specimen Dimensions:

Length, L: 1.5 in
 Diameter, D_1 : 1.1 in
 Diameter, D_2 : 0.9 in

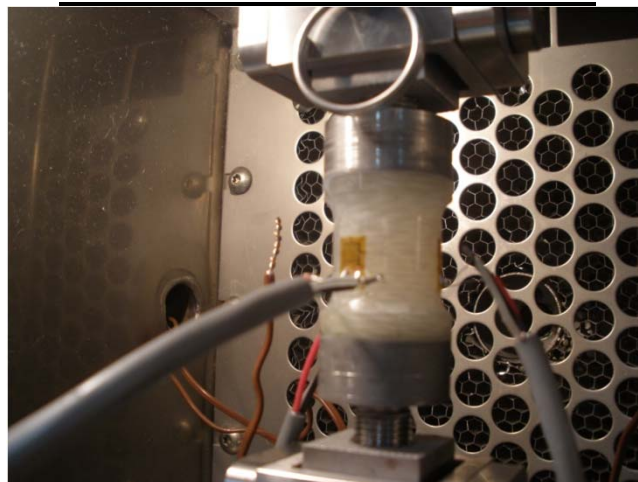
Laboratory Temperature: 68°F

Failure Mode: Rupture

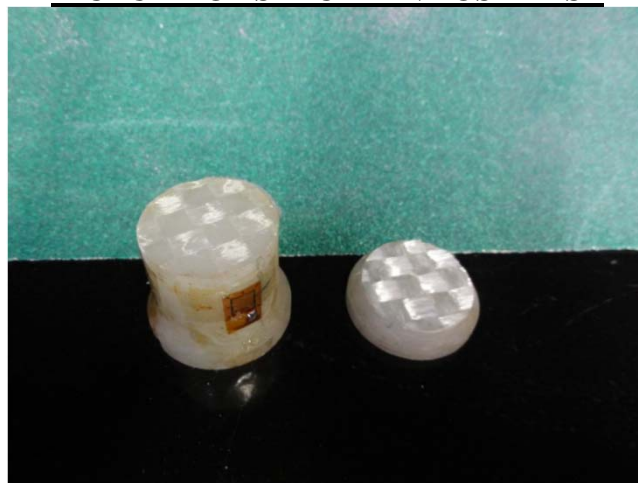
50% Max Stress: 1,291 psi

20% Max Stress: 516 psi

PICTURE OF SPECIMEN PRE-TEST



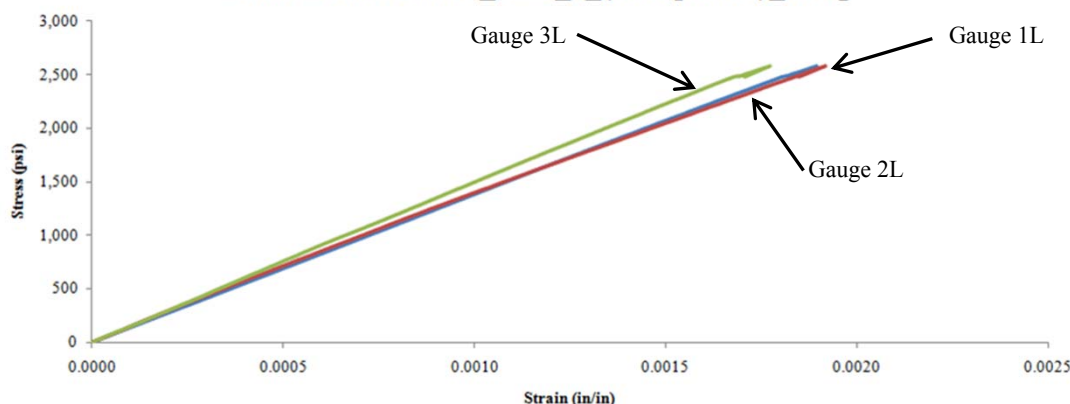
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000930 | 0.000371 | 1,386,401 |
| 2L | 0.000916 | 0.000354 | 1,378,139 |
| 3L | 0.000859 | 0.000341 | 1,494,518 |
| Average | | | 1,419,686 |

Stress-Strain Curve_70°F_2_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-3-70**
 Test Date: 3/23/2011
 Specimen Received: 1/13/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,203 psi
 Tensile Modulus, E_z : 1,390,976 psi

Measured Specimen Dimensions:

Length, L: 1.5 in
 Diameter, D_1 : 1.1 in
 Diameter, D_2 : 0.9 in

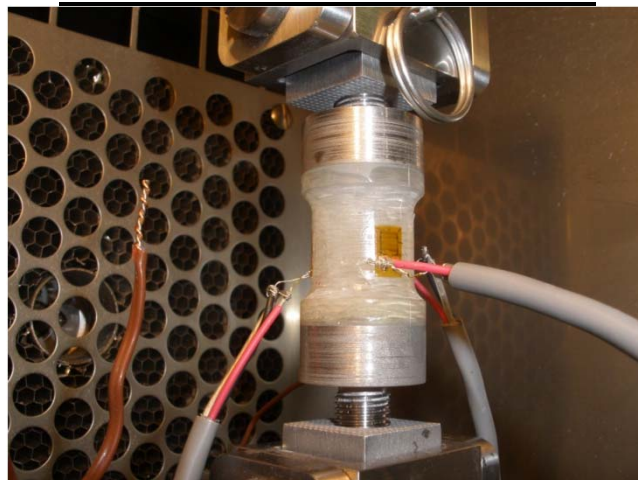
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,101 psi

20% Max Stress: 441 psi

PICTURE OF SPECIMEN PRE-TEST



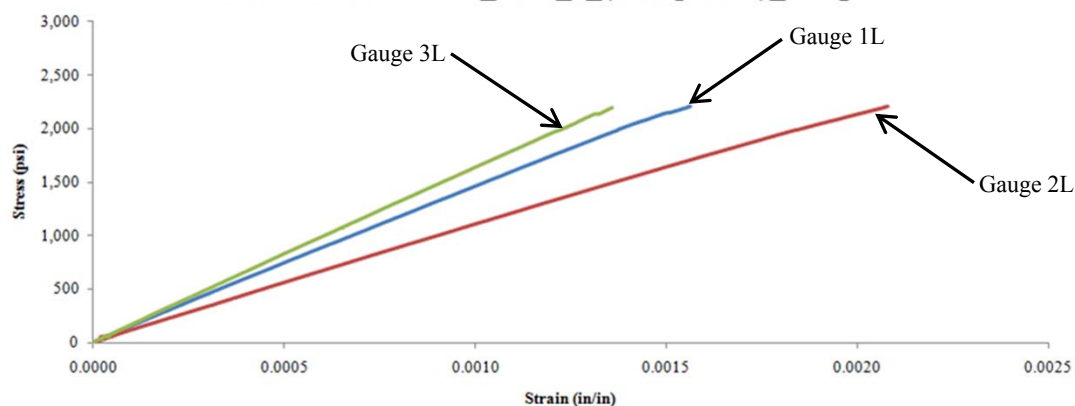
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000747 | 0.000288 | 1,439,865 |
| 2L | 0.000995 | 0.000390 | 1,092,861 |
| 3L | 0.000665 | 0.000262 | 1,640,201 |
| Average | | | 1,390,976 |

Stress-Strain Curve_70°F_3_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-4-70**
 Test Date: 3/23/2011
 Specimen Received: 1/13/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,476 psi
 Tensile Modulus, E_z : 1,515,977 psi

Measured Specimen Dimensions:

Length, L: 1.5 in
 Diameter, D_1 : 1.1 in
 Diameter, D_2 : 0.9 in

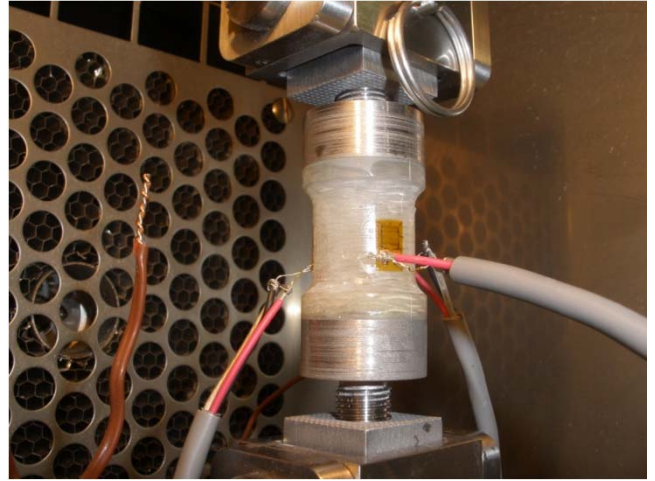
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,238 psi

20% Max Stress: 495 psi

PICTURE OF SPECIMEN PRE-TEST



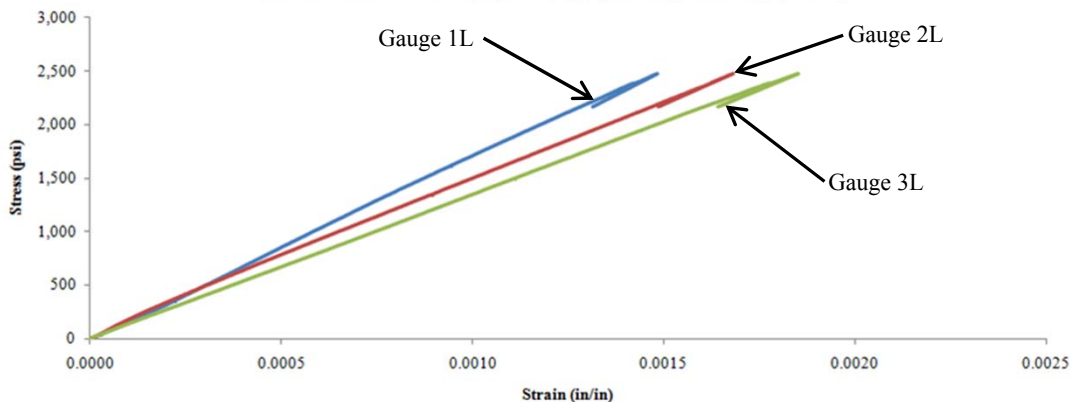
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000719 | 0.000299 | 1,768,594 |
| 2L | 0.000816 | 0.000299 | 1,436,648 |
| 3L | 0.000920 | 0.000367 | 1,342,689 |
| Average | | | 1,515,977 |

Stress-Strain Curve_70°F_4_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-5-70**
 Test Date: 3/25/2011
 Specimen Received: 1/13/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,135 psi
 Tensile Modulus, E_z : 1,212,464 psi

Measured Specimen Dimensions:

Length, L: 1.5 in
 Diameter, D_1 : 1.1 in
 Diameter, D_2 : 0.9 in

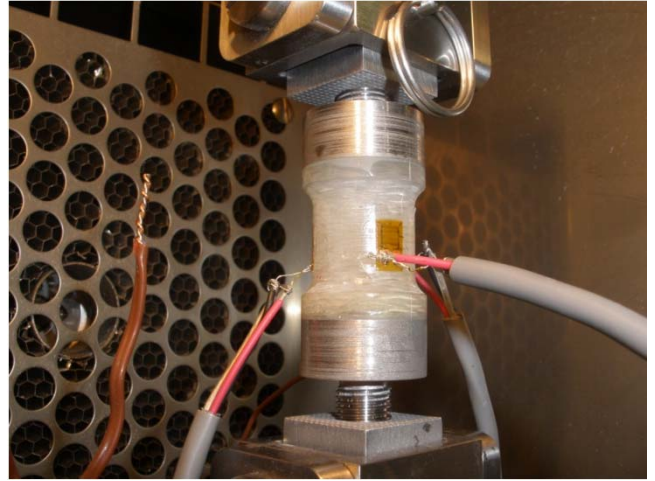
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 1,067 psi

20% Max Stress: 427 psi

PICTURE OF SPECIMEN PRE-TEST



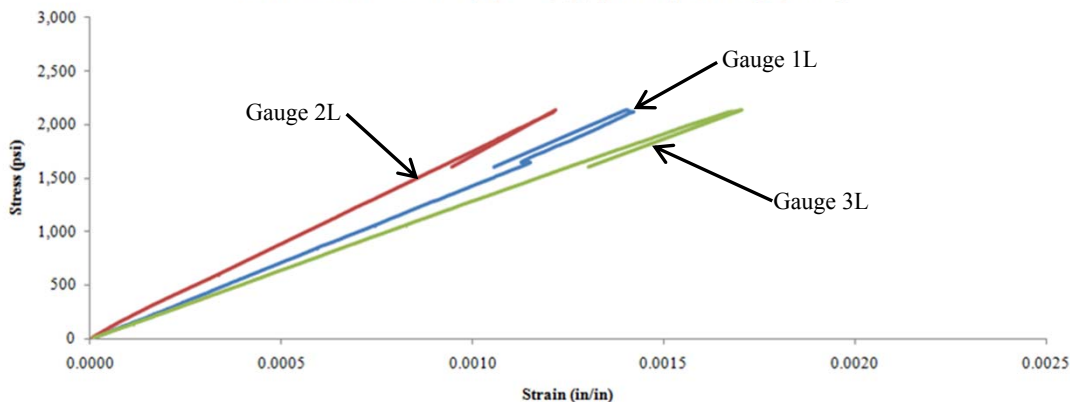
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|----------------------------|----------------------------|--------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus |
| | ϵ , (in/in) | ϵ , (in/in) | E_z , (psi) |
| 1L | 0.000924 | 0.000378 | 1,173,787 |
| 2L | 0.000750 | 0.000295 | 1,408,775 |
| 3L | 0.001027 | 0.000420 | 1,054,832 |
| Average | | | 1,212,464 |

Stress-Strain Curve_70°F_5_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

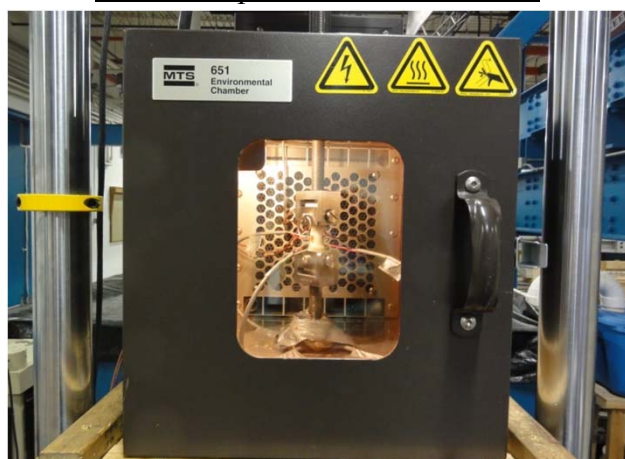
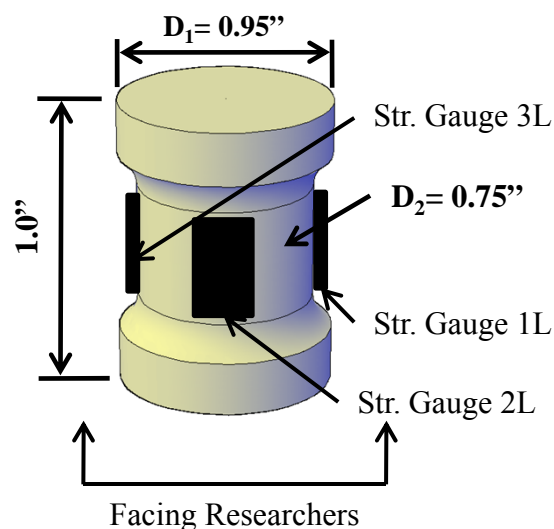
MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS**

Specimen ID Group: MATA-TZ-140_ (Spooled Specimens)
Material: Huntsman Epoxy Resin SC-15, S2 Glass
Nominal Temperature: 140°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Tensile Strength, ST_z : 1,256 psi
 Tensile Modulus, E_z : 1,282,549 psi

| TEST | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|----------------|-----------------------------------|---------------------------------|--------------|
| MATA-TZ-1-140 | 679 | 1,492,984 | Rupture |
| MATA-TZ-2-140 | 1,325 | 1,036,008 | Rupture |
| MATA-TZ-3-140 | 1,409 | 1,359,646 | Rupture |
| MATA-TZ-4-140 | 1,495 | 1,247,269 | Rupture |
| MATA-TZ-5-140 | 1,373 | 1,276,840 | Rupture |
| Average | 1,256 | 1,282,549 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and elastic modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a 0.95 inch diameter cylinder with a reduced gauge section of 0.75 inch diameter. Three longitudinal strain gages are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow universal tension. This test is performed on the Instron 8502A

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference A-68 to A-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-1-140**
 Test Date: 6/15/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 679 psi
 Tensile Modulus, E_z : 1,492,984 psi

Measured Specimen Dimensions:

Length, L: 0.902 in
 Diameter, D_1 : 0.953 in
 Diameter, D_2 : 0.753 in

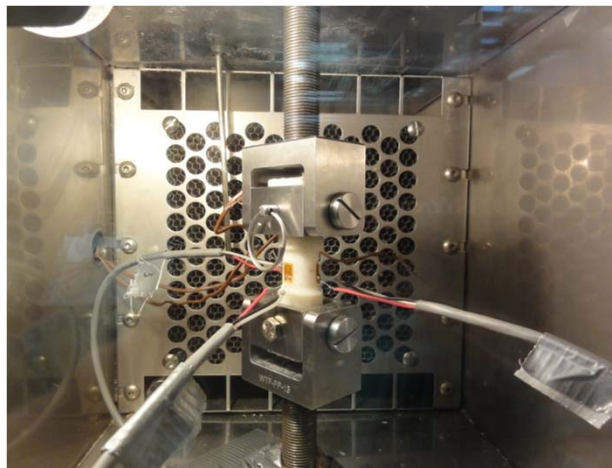
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 339 psi

20% Max Stress: 136 psi

PICTURE OF SPECIMEN PRE-TEST



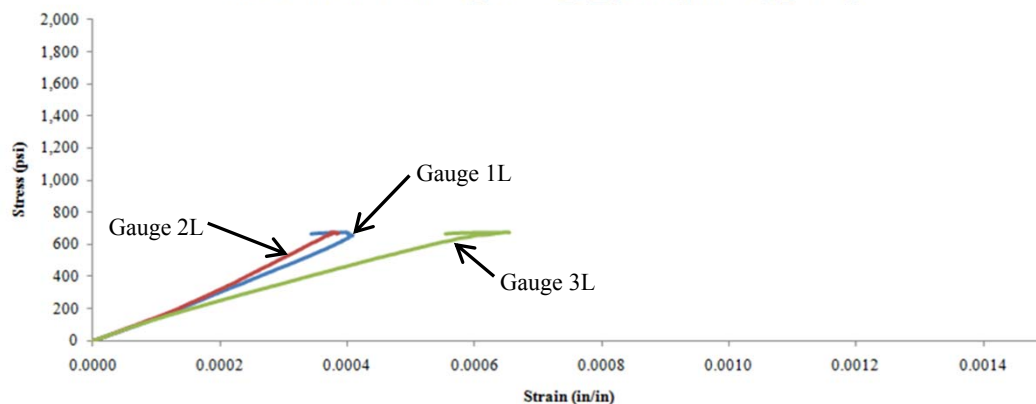
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000221 | 0.000094 | 1,609,551 |
| 2L | 0.000210 | 0.000092 | 1,735,489 |
| 3L | 0.000279 | 0.000099 | 1,133,911 |
| Average | | | 1,492,984 |

Stress-Strain Curve_140°F_1_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-2-140**
 Test Date: 6/15/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,325 psi
 Tensile Modulus, E_z : 1,036,008 psi

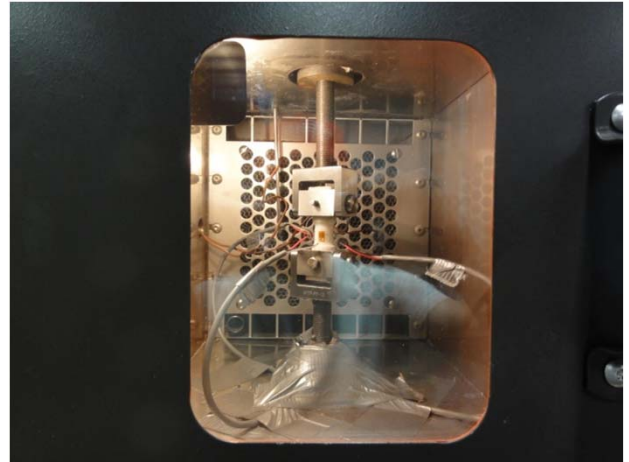
Measured Specimen Dimensions:

Length, L: 0.902 in
 Diameter, D_1 : 0.948 in
 Diameter, D_2 : 0.748 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture

50% Max Stress: 663 psi
 20% Max Stress: 265 psi

PICTURE OF SPECIMEN PRE-TEST



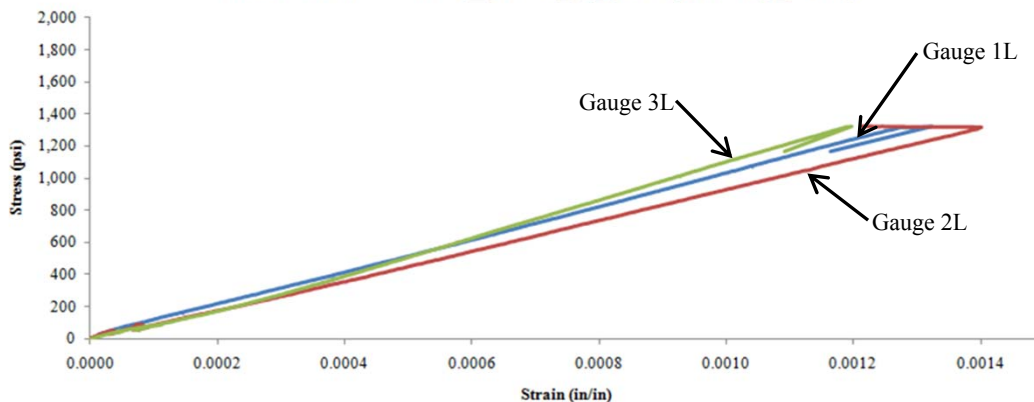
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000643 | 0.000244 | 996,714 |
| 2L | 0.000722 | 0.000300 | 941,253 |
| 3L | 0.000626 | 0.000286 | 1,170,056 |
| Average | | | 1,036,008 |

Stress-Strain Curve_140°F_2_(Acceptance)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-3-140**
 Test Date: 6/16/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,409 psi
 Tensile Modulus, E_z : 1,359,646 psi

Measured Specimen Dimensions:

Length, L: 0.902 in
 Diameter, D_1 : 0.953 in
 Diameter, D_2 : 0.749 in

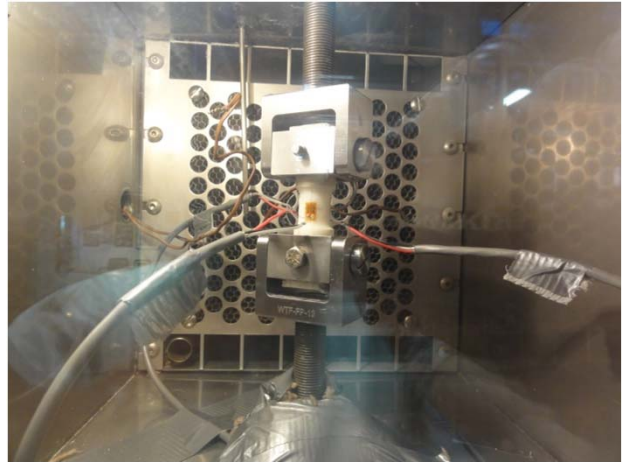
Laboratory Temperature: 68°F

Failure Mode: Rupture

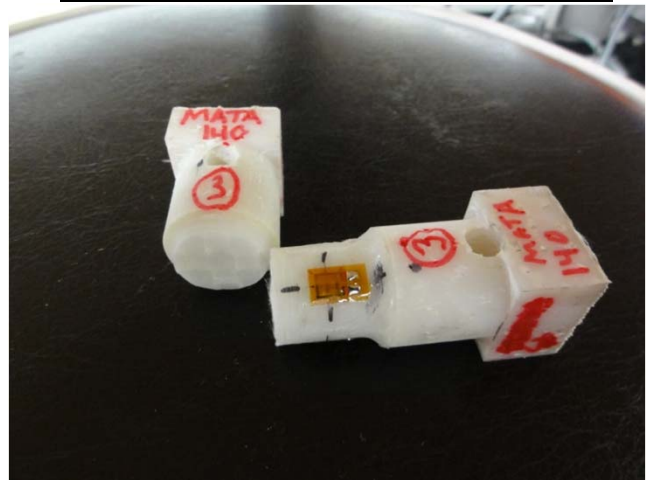
50% Max Stress: 705 psi

20% Max Stress: 282 psi

PICTURE OF SPECIMEN PRE-TEST



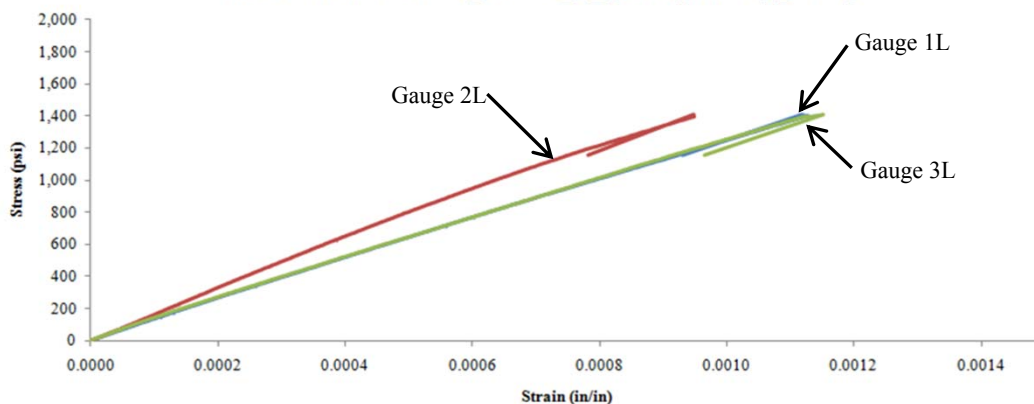
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000546 | 0.000207 | 1,245,014 |
| 2L | 0.000433 | 0.000169 | 1,597,873 |
| 3L | 0.000546 | 0.000204 | 1,236,051 |
| Average | | | 1,359,646 |

Stress-Strain Curve_140°F_3_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-4-140**
 Test Date: 6/16/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,495 psi
 Tensile Modulus, E_z : 1,247,269 psi

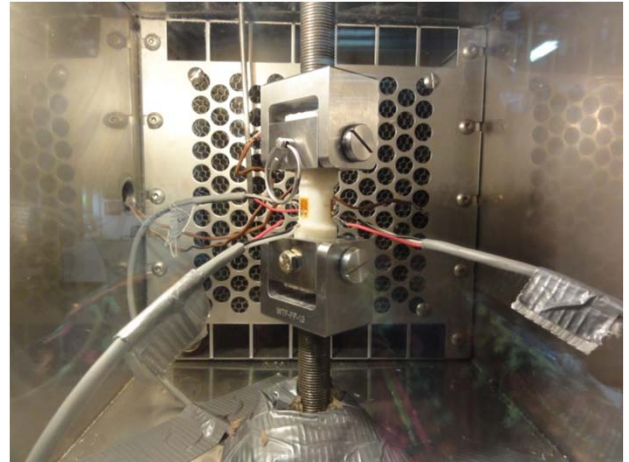
Measured Specimen Dimensions:

Length, L: 0.902 in
 Diameter, D_1 : 0.949 in
 Diameter, D_2 : 0.748 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture

50% Max Stress: 747 psi
 20% Max Stress: 299 psi

PICTURE OF SPECIMEN PRE-TEST



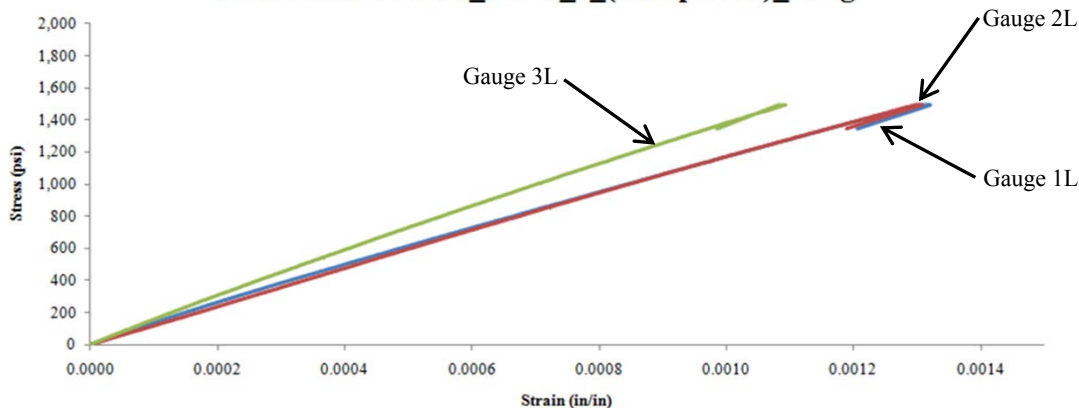
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000615 | 0.000226 | 1,153,340 |
| 2L | 0.000626 | 0.000248 | 1,187,523 |
| 3L | 0.000511 | 0.000191 | 1,400,945 |
| Average | | | 1,247,269 |

Stress-Strain Curve_140°F_4_(Acceptance)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-TZ-5-140**
 Test Date: 6/16/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,373 psi
 Tensile Modulus, E_z : 1,276,840 psi

Measured Specimen Dimensions:

Length, L: 0.902 in
 Diameter, D_1 : 0.949 in
 Diameter, D_2 : 0.748 in

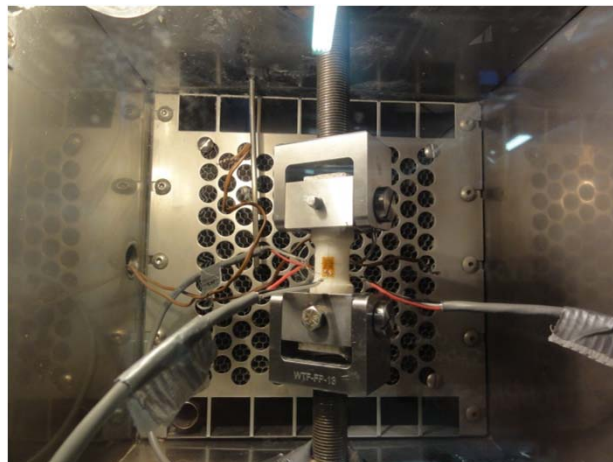
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 687 psi

20% Max Stress: 275 psi

PICTURE OF SPECIMEN PRE-TEST



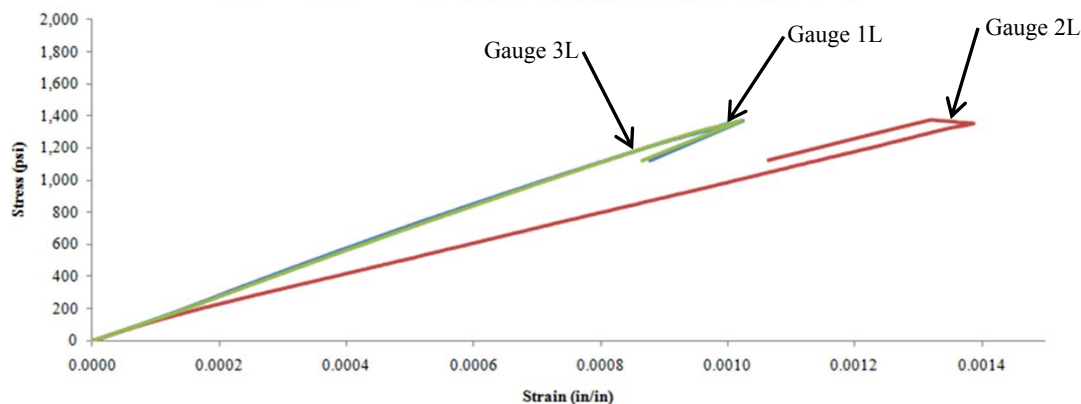
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000475 | 0.000192 | 1,454,543 |
| 2L | 0.000681 | 0.000244 | 944,072 |
| 3L | 0.000485 | 0.000197 | 1,431,904 |
| Average | | | 1,276,840 |

Stress-Strain Curve_140°F_5_(Acceptance)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

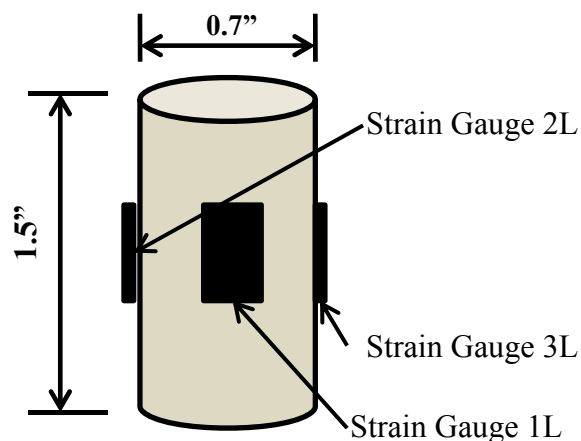
Specimen ID Group: MATA-CZ-N40
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: -40°F
 Properties Measured: SC_z , E_z , ϵ_z

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_z : | 39,340 | lbs |
| Compressive Strength, SC_z : | 110,720 | psi |
| Compressive Modulus, E_z : | 1,395,380 | psi |
| Ultimate Strain, ϵ_z : | 0.081 | in/in |

| TEST | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|----------------|---------------------------|------------------------------|----------------------------------|---------------------------------------|--------------|
| MATA-CZ-01-N40 | 42,877 | 117,471 | 1,360,740 | 0.086 | Rupture |
| MATA-CZ-02-N40 | 39,026 | 108,407 | 1,029,422 | 0.106 | Rupture |
| MATA-CZ-03-N40 | 36,991 | 117,806 | 1,675,647 | 0.070 | Rupture |
| MATA-CZ-04-N40 | 40,567 | 107,890 | 1,486,961 | 0.073 | Rupture |
| MATA-CZ-05-N40 | 37,239 | 102,024 | 1,424,130 | 0.072 | Rupture |
| Average | 39,340 | 110,720 | 1,395,380 | 0.081 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Facing Researchers****Notes:**

- 1) Reference A-74 to A-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-01-N40**
 Test Date: 4/18/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 42,877 lbs
 Maximum Stress, SC_z : 117,471 psi
 Elastic Modulus, E_z : 1,360,740 psi
 Ultimate Strain, ϵ_z : 0.086 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.25 in
 Diameter, D: 0.68 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 8,575 psi
 50% Max Load: 21,438 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | Lost Gauge | Lost Gauge | - |
| 2L | -0.041 | -0.015 | 1,360,740 |
| 3L | Lost Gauge | Lost Gauge | - |
| Average | | | 1,360,740 |

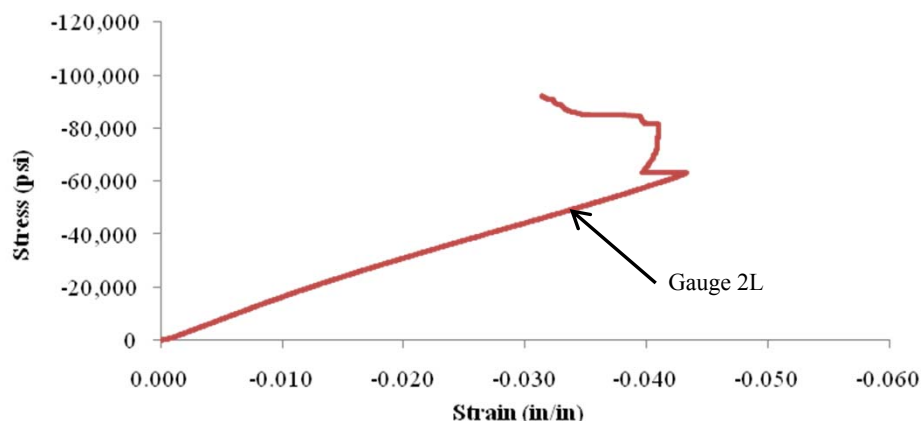
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve CZ_N40_01_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Gauge one and three lost before 50% Max Load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-02-N40**
 Test Date: 4/18/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 39,026 lbs
 Maximum Stress, SC_z : 108,407 psi
 Elastic Modulus, E_z : 1,029,422 psi
 Ultimate Strain, ϵ_z : 0.106 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.21 in
 Diameter, D: 0.68 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 7,805 psi
 50% Max Load: 19,513 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.030 | -0.011 | 1,685,845 |
| 2L | -0.036 | -0.013 | 1,407,081 |
| 3L | Lost Gauge | Lost Gauge | - |
| Average | | | 1,546,463 |

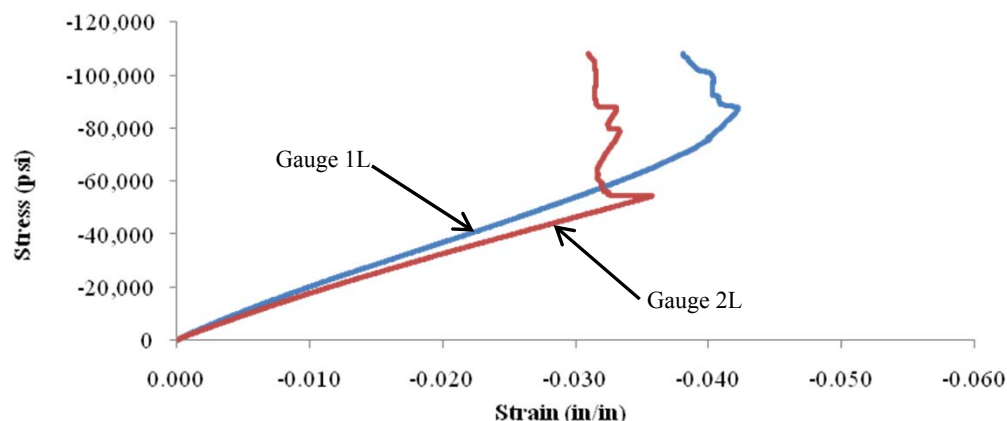
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve CZ_N40_02_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Strain Three lost before 50% Max Load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-03-N40**
 Test Date: 4/18/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 36,991 lbs
 Maximum Stress, SC_z : 117,806 psi
 Elastic Modulus, E_z : 1,675,647 psi
 Ultimate Strain, ϵ_z : 0.070 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.29 in
 Diameter, D: 0.63 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 7,398 psi
 50% Max Load: 18,469 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | Lost Gauge | Lost Gauge | - |
| 2L | -0.033 | -0.012 | 1,706,586 |
| 3L | -0.033 | -0.012 | 1,644,708 |
| Average | | | 1,675,647 |

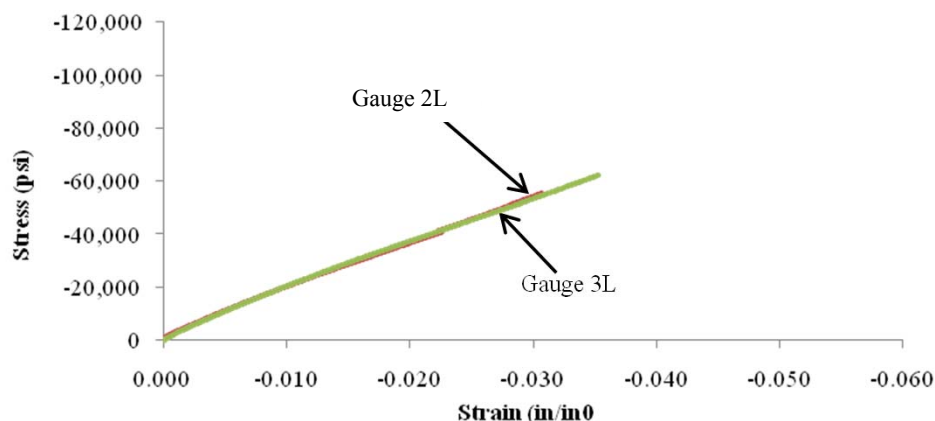
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve CZ_N40_03_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Strain One lost before 50% Max Load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-04-N40**
 Test Date: 4/18/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 40,567 lbs
 Maximum Stress, SC_z : 107,890 psi
 Elastic Modulus, E_z : 1,486,961 psi
 Ultimate Strain, ϵ_z : 0.073 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.28 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 8,113 psi
 50% Max Load: 20,283 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | Lost Gauge | Lost Gauge | - |
| 2L | -0.035 | -0.013 | 1,486,961 |
| 3L | Lost Gauge | Lost Gauge | - |
| Average | | | 1,486,961 |

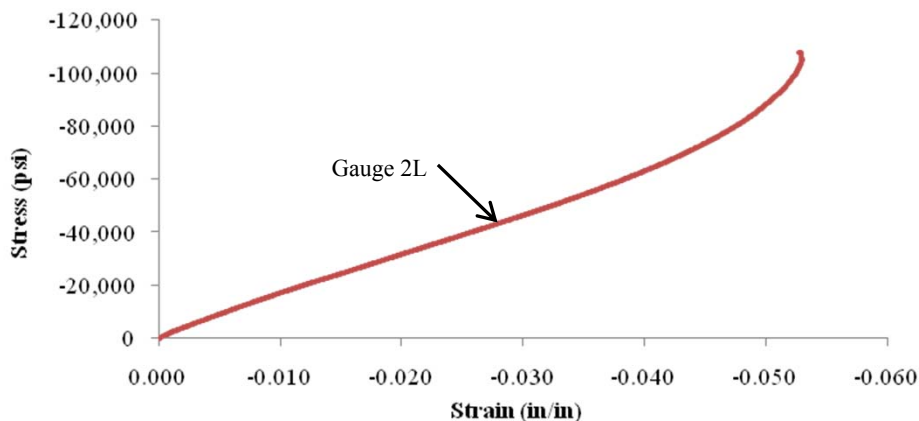
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve CZ_N40_04_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Gauges one and three was lost before 50% max load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-05-N40**
 Test Date: 4/18/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 37,239 lbs
 Maximum Stress, SC_z : 102,024 psi
 Elastic Modulus, E_z : 1,424,130 psi
 Ultimate Strain, ϵ_z : 0.072 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.27 in
 Diameter, D: 0.68 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 7,448 psi
 50% Max Load: 19,619 psi

PICTURE OF SPECIMEN PRE-TEST



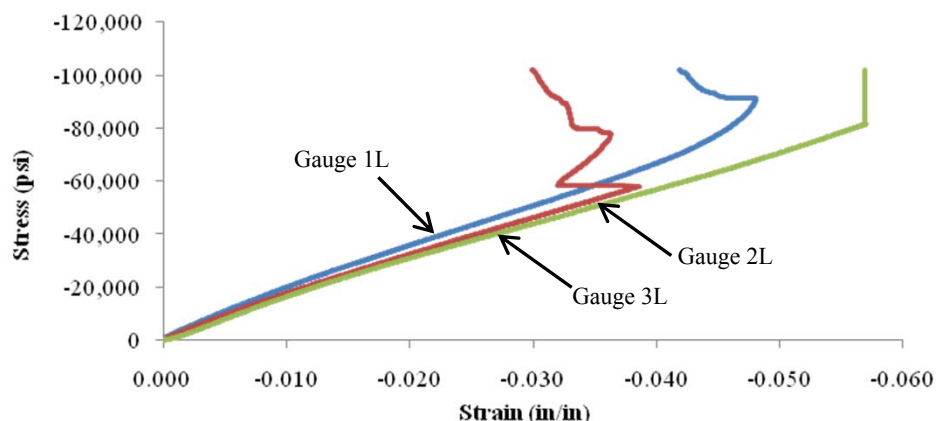
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.030 | -0.010 | 1,534,487 |
| 2L | -0.034 | -0.012 | 1,402,754 |
| 3L | -0.035 | -0.013 | 1,335,148 |
| Average | | | 1,424,130 |

Stress-Strain Curve CZ_N40_05_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

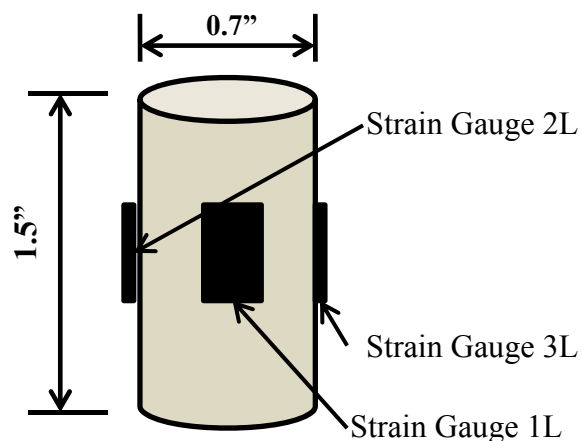
Specimen ID Group: MATA-CZ-70
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: 70°F
 Properties Measured: SC_z , E_z , ϵ_z

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_z : | 32,783 | lbs |
| Compressive Strength, SC_z : | 88,327 | psi |
| Compressive Modulus, E_z : | 1,181,799 | psi |
| Ultimate Strain, ϵ_z : | 0.076 | in/in |

| TEST | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|----------------|---------------------------|------------------------------|----------------------------------|---------------------------------------|--------------|
| MATA-CZ-01-70 | 32,811 | 87,729 | 1,110,282 | 0.080 | Rupture |
| MATA-CZ-02-70 | 33,617 | 89,891 | 1,166,510 | 0.077 | Rupture |
| MATA-CZ-03-70 | 31,276 | 83,626 | 1,158,780 | 0.074 | Rupture |
| MATA-CZ-04-70 | 32,222 | 88,280 | 1,306,079 | 0.068 | Rupture |
| MATA-CZ-05-70 | 33,987 | 92,108 | 1,167,343 | 0.080 | Rupture |
| Average | 32,783 | 88,327 | 1,181,799 | 0.076 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

Facing Researchers

Notes:

- 1) Reference A-80 to A-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-01-70**
 Test Date: 4/8/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 32,811 lbs
 Maximum Stress, SC_z : 87,729 psi
 Elastic Modulus, E_z : 1,110,282 psi
 Ultimate Strain, ϵ_z : 0.080 in/in

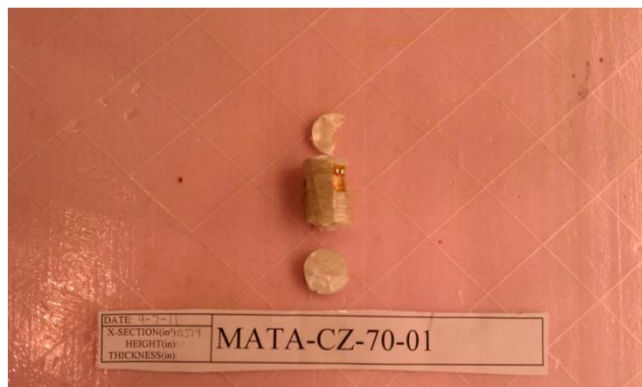
Measured/Nominal Specimen Dimensions:

Length, L: 1.38 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,562 psi
 50% Max Load: 16,405 psi

PICTURE OF SPECIMEN PRE-TEST



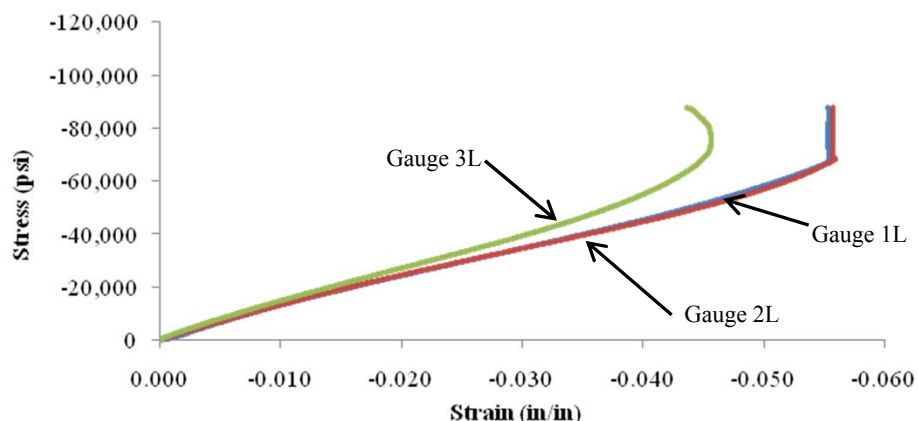
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.039 | -0.014 | 1,056,761 |
| 2L | -0.039 | -0.014 | 1,029,712 |
| 3L | -0.033 | -0.012 | 1,244,372 |
| Average | | | 1,110,282 |

Stress-Strain Curve_CZ_70F_01_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-02-70**
 Test Date: 4/8/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 33,619 lbs
 Maximum Stress, SC_z : 89,891 psi
 Elastic Modulus, E_z : 1,165,510 psi
 Ultimate Strain, ϵ_z : 0.077 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.38 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,724 psi
 50% Max Load: 16,810 psi

PICTURE OF SPECIMEN PRE-TEST



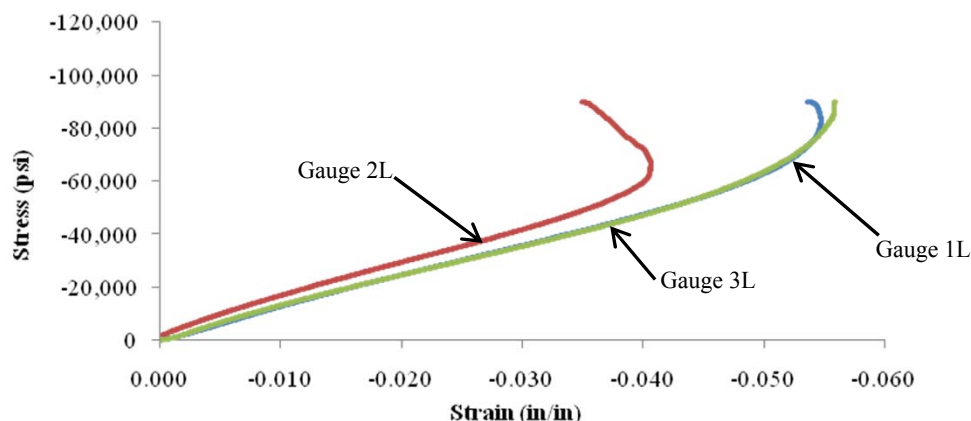
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.038 | -0.014 | 1,133,356 |
| 2L | -0.033 | -0.011 | 1,253,662 |
| 3L | -0.038 | -0.014 | 1,112,512 |
| Average | | | 1,166,510 |

Stress-Strain Curve_CZ_70F_02_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-03-70**
 Test Date: 4/13/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 31,276 lbs
 Maximum Stress, SC_z : 83,626 psi
 Elastic Modulus, E_z : 1,158,780 psi
 Ultimate Strain, ϵ_z : 0.074 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.30 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,255 psi
 50% Max Load: 15,638 psi

PICTURE OF SPECIMEN PRE-TEST



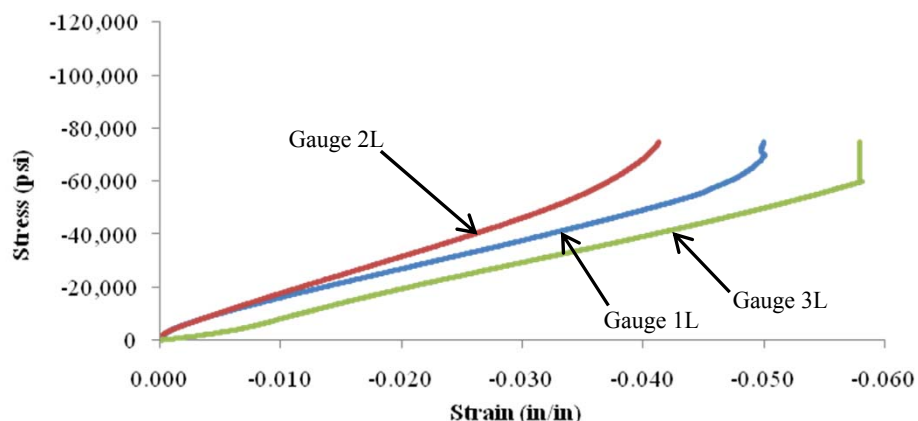
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.034 | -0.011 | 1,079,971 |
| 2L | -0.027 | -0.009 | 1,399,983 |
| 3L | -0.043 | -0.017 | 996,386 |
| Average | | | 1,158,780 |

Stress-Strain Curve 70F_02_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-04-70**
 Test Date: 4/13/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 32,222 lbs
 Maximum Stress, SC_z : 88,280 psi
 Elastic Modulus, E_z : 1,306,079 psi
 Ultimate Strain, ϵ_z : 0.068 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.19 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,444 psi
 50% Max Load: 16,111 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.032 | -0.011 | 1,257,873 |
| 2L | Lost Gauge | Lost Gauge | - |
| 3L | -0.033 | -0.013 | 1,354,285 |
| Average | | | 1,306,079 |

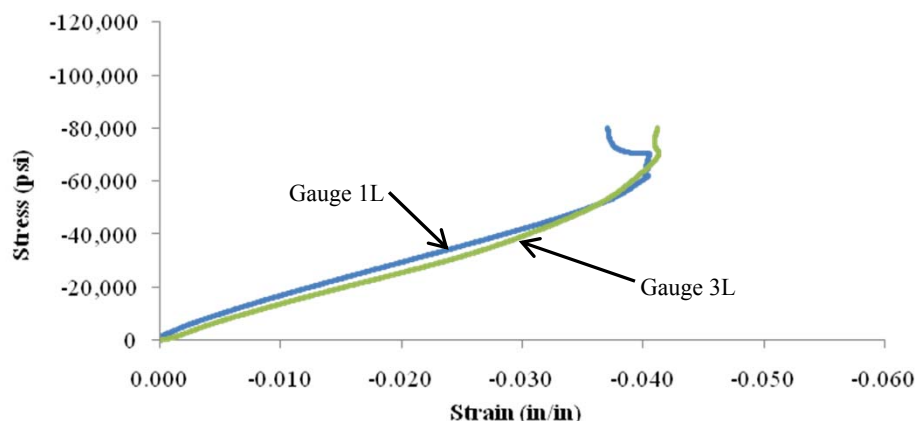
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_04_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Gauge 2L was lost before 50% max load was reached.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-05-70**
 Test Date: 4/13/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 33,988 lbs
 Maximum Stress, SC_z : 92,108 psi
 Elastic Modulus, E_z : 1,167,343 psi
 Ultimate Strain, ϵ_z : 0.080 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.30 in
 Diameter, D: 0.68 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,798 psi
 50% Max Load: 16,994 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.038 | -0.011 | 1,023,500 |
| 2L | -0.037 | -0.016 | 1,311,185 |
| 3L | Lost Gauge | Lost Gauge | - |
| Average | | | 1,167,343 |

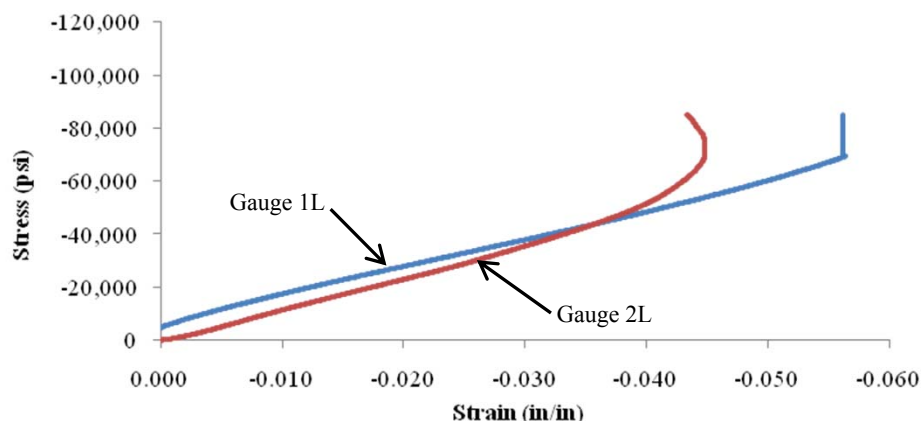
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_05_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Gauge 3L was lost before 50% max load was reached.

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

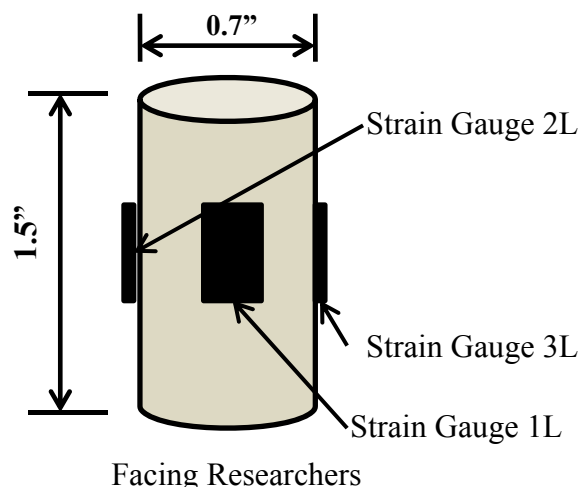
Specimen ID Group: MATA-CZ-140
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_z : | 29,409 | lbs |
| Compressive Strength, SC_z : | 79,397 | psi |
| Compressive Modulus, E_z : | 1,162,693 | psi |
| Ultimate Strain, ϵ_z : | 0.069 | in/in |

| TEST | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|----------------|------------------------------|---------------------------------|-------------------------------------|--|--------------|
| MATA-CZ-01-70 | 29,521 | 79,788 | 1,188,367 | 0.068 | Rupture |
| MATA-CZ-02-70 | 29,131 | 78,732 | 1,156,377 | 0.068 | Rupture |
| MATA-CZ-03-70 | 29,527 | 79,803 | 1,158,771 | 0.070 | Rupture |
| MATA-CZ-04-70 | 28,718 | 77,617 | 1,118,067 | 0.069 | Rupture |
| MATA-CZ-05-70 | 30,149 | 81,044 | 1,191,883 | 0.072 | Rupture |
| Average | 29,409 | 79,397 | 1,162,693 | 0.069 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference A-86 to A-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-01-140**
 Test Date: 4/19/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 29,521 lbs
 Maximum Stress, SC_z : 79,788 psi
 Elastic Modulus, E_z : 1,188,367 psi
 Ultimate Strain, ϵ_z : 0.068 in/in

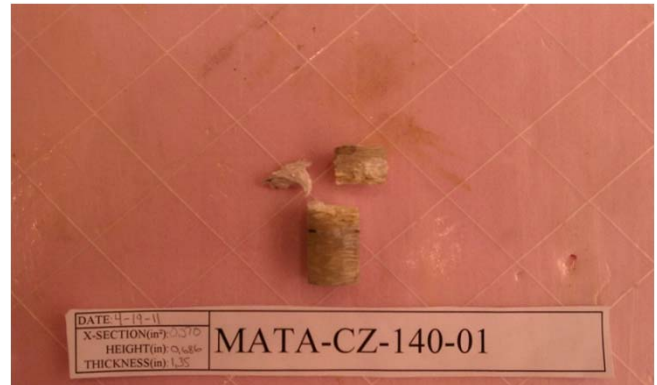
Measured/Nominal Specimen Dimensions:

Length, L: 1.35 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 5,904 psi
 50% Max Load: 14,761 psi

PICTURE OF SPECIMEN PRE-TEST



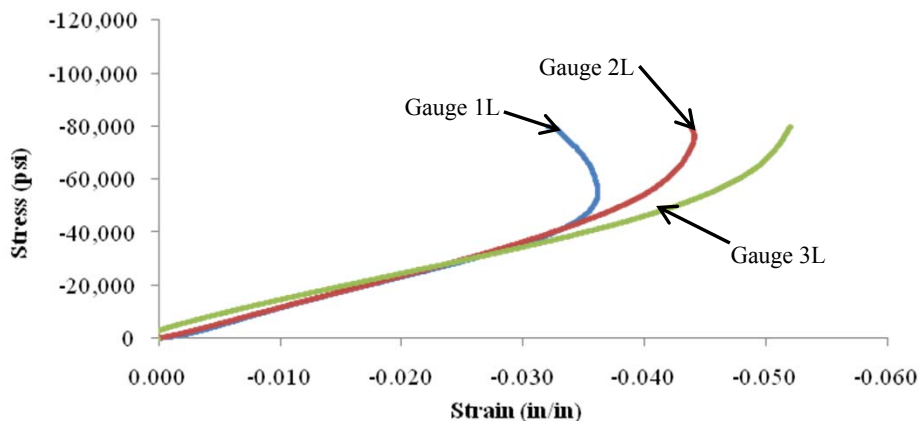
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.033 | -0.014 | 1,274,185 |
| 2L | -0.032 | -0.014 | 1,278,471 |
| 3L | -0.035 | -0.012 | 1,012,443 |
| Average | | | 1,188,367 |

Stress-Strain Curve CZ_140F_01_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-02-140**
 Test Date: 4/19/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 29,131 lbs
 Maximum Stress, SC_z : 78,732 psi
 Elastic Modulus, E_z : 1,156,377 psi
 Ultimate Strain, ϵ_z : 0.068 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.26 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 5,826 psi
 50% Max Load: 14,565 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.034 | -0.013 | 1,142,728 |
| 2L | Lost Gauge | Lost Gauge | - |
| 3L | -0.031 | -0.011 | 1,170,025 |
| Average | | | 1,156,377 |

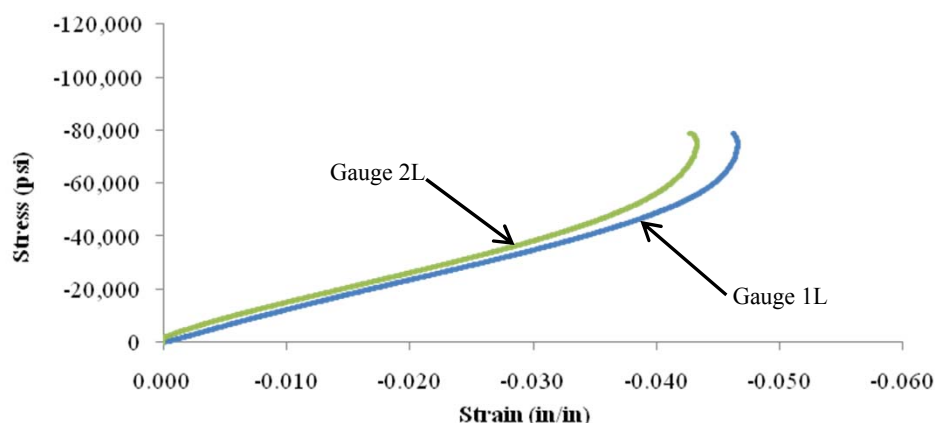
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve_CZ_140F_02_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).
- *Gauge two was lost before 50% Max Load.

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-03-140**
 Test Date: 4/19/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 29,527 lbs
 Maximum Stress, SC_z : 79,803 psi
 Elastic Modulus, E_z : 1,158,780 psi
 Ultimate Strain, ϵ_z : 0.070 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.26 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 5,905 psi
 50% Max Load: 14,763 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.028 | -0.010 | 1,321,80 |
| 2L | -0.038 | -0.015 | 1,033,476 |
| 3L | -0.036 | -0.014 | 1,121,457 |
| Average | | | 1,158,771 |

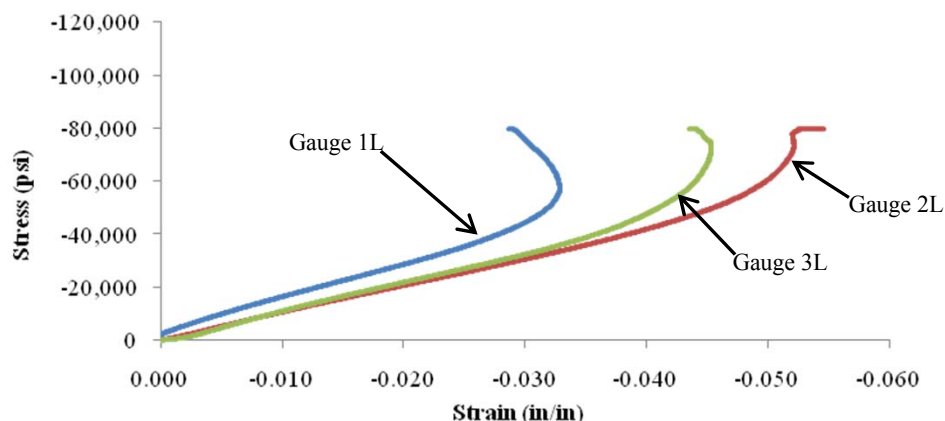
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve_CZ_140_03_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-04-140**
 Test Date: 4/20/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 28,718 lbs
 Maximum Stress, SC_z : 77,617 psi
 Elastic Modulus, E_z : 1,118,725 psi
 Ultimate Strain, ϵ_z : 0.069 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.24 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 5,744 psi
 50% Max Load: 14,359 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.028 | -0.010 | 1,321,380 |
| 2L | -0.038 | -0.010 | 1,033,476 |
| 3L | -0.036 | -0.014 | 1,121,457 |
| Average | | | 1,158,771 |

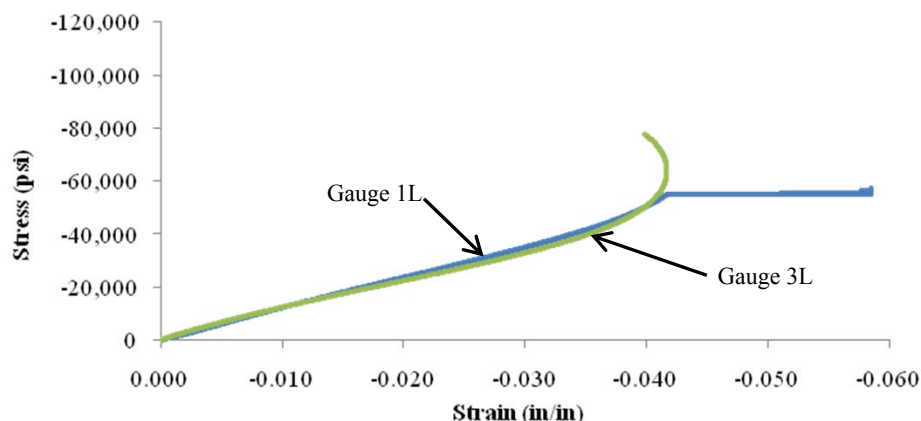
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve_CZ_140F_04_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-CZ-05-140**
 Test Date: 4/20/2011
 Specimen Received: 4/6/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 30,149 lbs
 Maximum Stress, SC_z : 81,044 psi
 Elastic Modulus, E_z : 1,191,883 psi
 Ultimate Strain, ϵ_z : 0.072 in/in

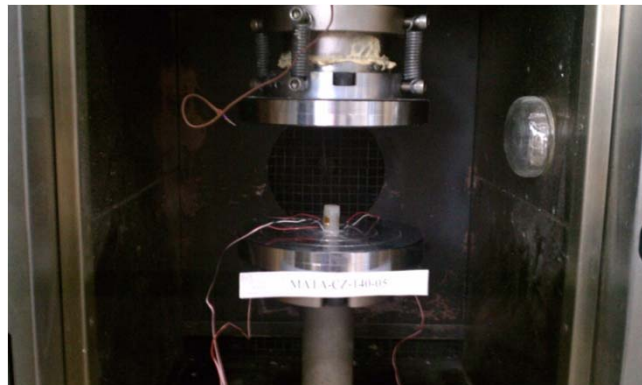
Measured/Nominal Specimen Dimensions:

Length, L: 1.11 in
 Diameter, D: 0.69 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 20% Max Load: 6,030 psi
 50% Max Load: 15,074 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.033 | -0.007 | 943,139 |
| 2L | -0.044 | -0.021 | 1,023,283 |
| 3L | -0.031 | -0.016 | 1,609,226 |
| Average | | | 1,191,883 |

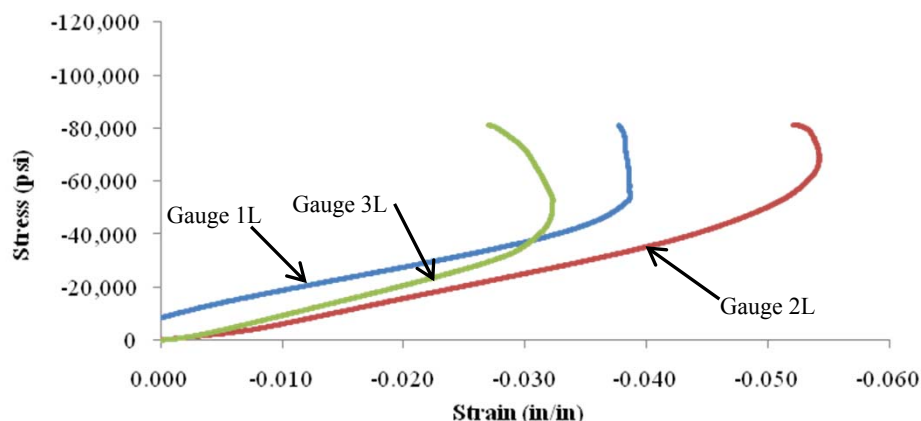
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve CZ_140_05_MATA, Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-SXZ-N40
 Material: Acceptance Material
 Nominal Temperature: -40°F
 Properties Measured: G_{xz} , S_{xz}
 Average Material Properties (5 Specimens):

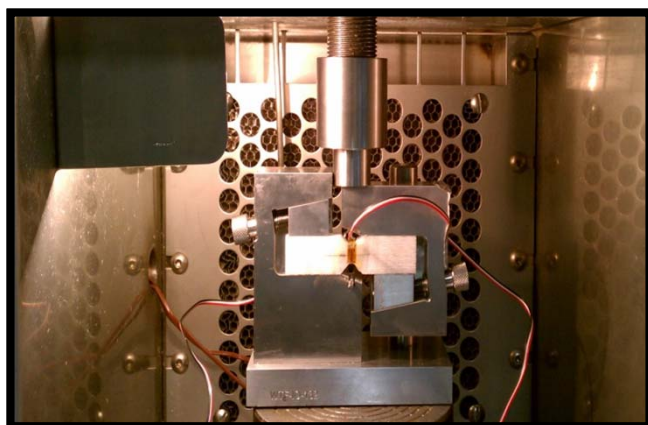
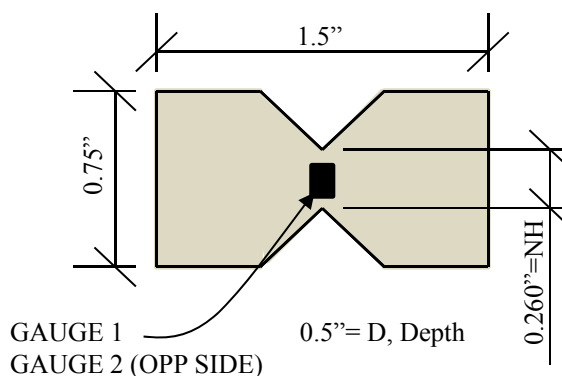
| | | |
|----------------------------|---------|-----|
| Ultimate Load, P_{max} : | 572 | lbs |
| Shear Strength, S_{xz} : | 4,877 | psi |
| Shear Modulus, G_{xz} : | 948,947 | psi |

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|-----------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 10 | MATA-SXZ-N40-10 | 621 | 5,159 | 1,015,325 | Shear |
| 11 | MATA-SXZ-N40-11 | 548 | 4,962 | 1,040,623 | Shear |
| 12 | MATA-SXZ-N40-12 | 510 | 3,998 | 762,323 | Shear |
| 13 | MATA-SXZ-N40-13 | 619 | 5,112 | 1,037,322 | Shear |
| 14 | MATA-SXZ-N40-14 | 561 | 5,156 | 889,139 | Shear |
| Average | | 572 | 4,877 | 948,947 | Shear |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379, measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear chord modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane.

The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.015 in/min will be used for the best data acquisition. The ultimate strength is calculated using the lower of the maximum load at failure or the load at 5% shear strain.

-40°F Test Condition**Specimens Nominal Dimensions / Strain Gauge Location****FACING RESEARCHERS****Notes:**

- 1) Individual specimen results are shown on Sheets A-92 to A-96
- 2) Seven specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-010-N40
 Test Date: 4/19/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 621 lbs
 Shear Stress, S_{xz} : 5,159 psi
 Shear Modulus, G_{xz} : 1,015,325 psi

Measured Specimen Dimensions:

Depth, D: 0.491 in
 Notch Length, NH: 0.245 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 554 lbs
 Load @ .002 $\mu\epsilon$: 310 lbs

PICTURE OF SPECIMEN PRE-TEST



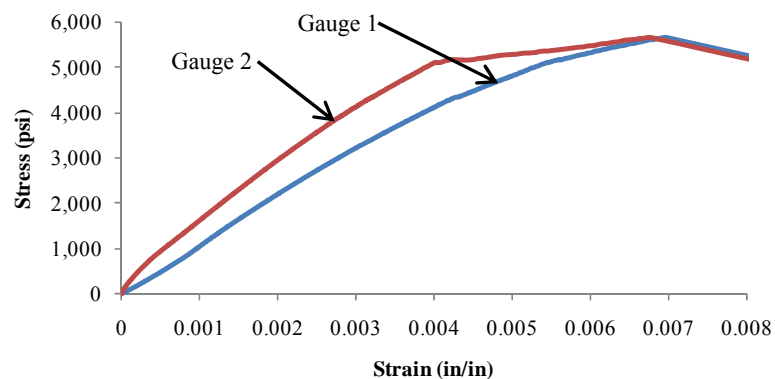
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 958,031 |
| 2 | 0.0040 | 0.0020 | 1,072,618 |
| Average | | | 1,015,325 |

Stress-Strain Curve N40_10A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-011-N40
 Test Date: 4/19/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 548 lbs
 Shear Stress, S_{xz} : 4,962 psi
 Shear Modulus, G_{xz} : 1,040,623 psi

Measured Specimen Dimensions:

Depth, D: 0.449 in
 Notch Length, NH: 0.246 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 503 lbs
 Load @ .002 $\mu\epsilon$: 273 lbs

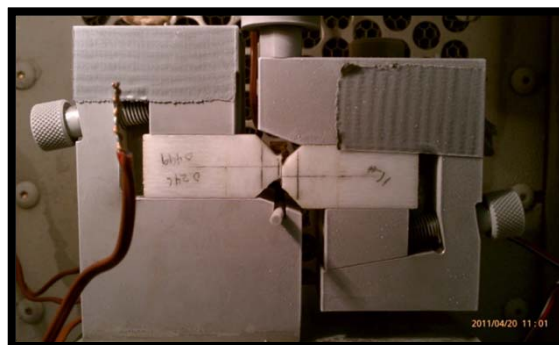
INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 1,027,591 |
| 2 | 0.0040 | 0.0020 | 1,053,656 |
| Average | | | 1,040,623 |

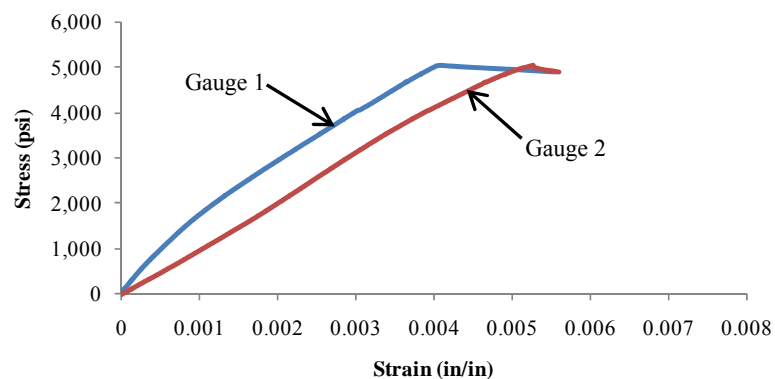
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_11A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 2A was calculated using the ultimate load

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-012-N40
 Test Date: 4/20/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 510 lbs
 Shear Stress, S_{xz} : 3,998 psi
 Shear Modulus, G_{xz} : 762,323 psi

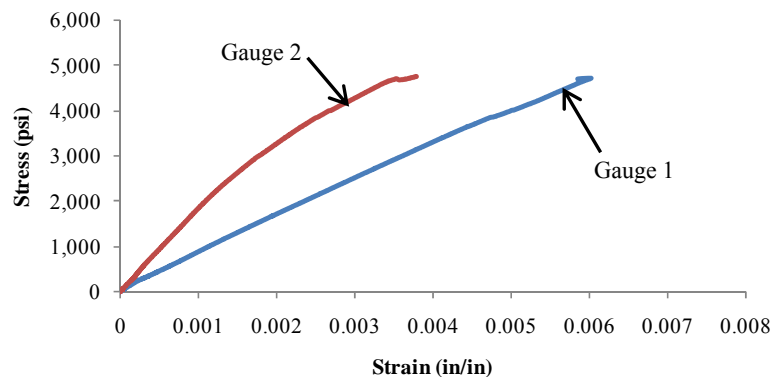
Measured Specimen Dimensions:

Depth, D: 0.491 in
 Notch Length, NH: 0.26 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 512 lbs
 Load @ .002 $\mu\epsilon$: 318 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 794,101 |
| 2 | 0.0040 | 0.0020 | 730,546 |
| Average | | | 762,323 |

Stress-Strain Curve N40_12A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 2A was calculated using the ultimate load

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-013-N40
 Test Date: 4/20/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 619 lbs
 Shear Stress, S_{xz} : 5,112 psi
 Shear Modulus, G_{xz} : 1,037,322 psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NH: 0.244 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 550 lbs
 Load @ .002 $\mu\epsilon$: 299 lbs

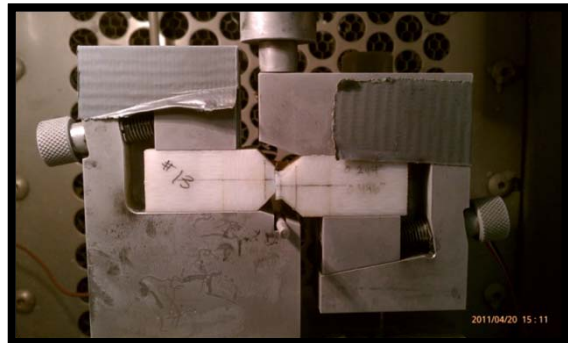
INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 1,096,433 |
| 2 | 0.0040 | 0.0020 | 978,212 |
| Average | | | 1,037,322 |

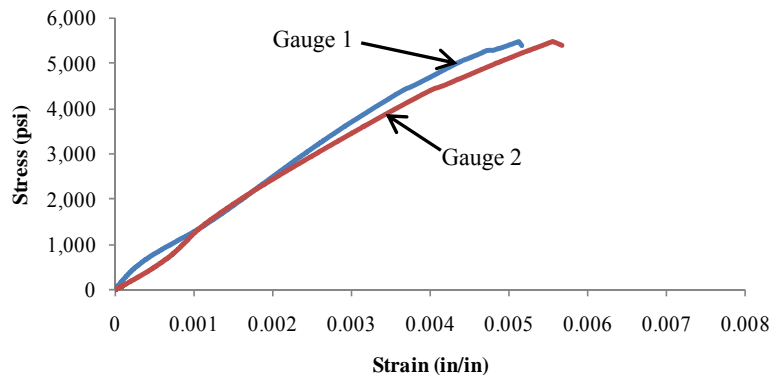
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_13A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 2A was calculated using the ultimate load

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-014-N40
 Test Date: 4/21/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 561 lbs
 Shear Stress, S_{xz} : 5,156 psi
 Shear Modulus, G_{xz} : 889,139 psi

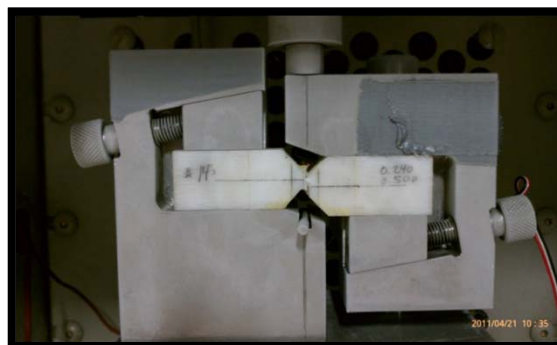
Measured Specimen Dimensions:

Depth, D: 0.5 in
 Notch Length, NH: 0.24 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 500 lbs
 Load @ .002 $\mu\epsilon$: 287 lbs

PICTURE OF SPECIMEN PRE-TEST



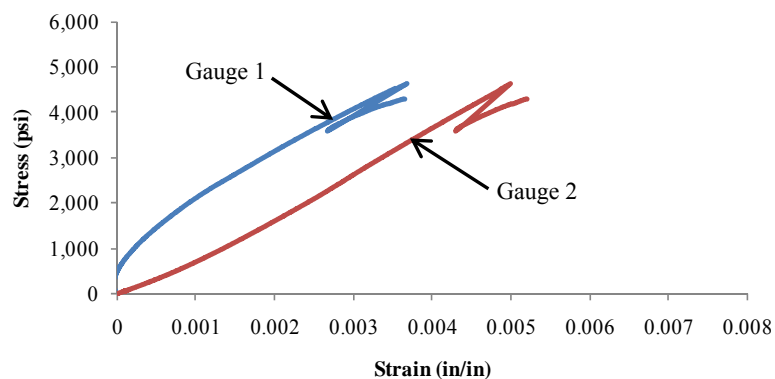
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 746,644 |
| 2 | 0.0040 | 0.0020 | 1,031,634 |
| Average | | | 889,139 |

Stress-Strain Curve N40_14A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 2A was calculated using the ultimate load

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-SXZ-70

Material: SC-15, S2 Glass

Nominal Temperature: 68°F

Properties Measured: G_{xz} , S_{xz}

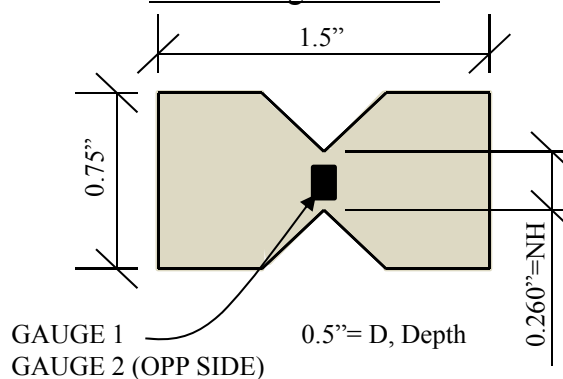
Average Material Properties (5 Specimens):

| | | |
|---|----------------|------------|
| Ultimate Load, P_{max}: | 581 | lbs |
| Shear Strength, S_{xz}: | 4,137 | psi |
| Shear Modulus, G_{xz}: | 820,919 | psi |

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|----------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MATA-SXZ-01-70 | 681 | 4,968 | 1,028,177 | Shear |
| 2 | MATA-SXZ-02-70 | 617 | 4,567 | 930,701 | Shear |
| 3 | MATA-SXZ-03-70 | 521 | 3,550 | 703,337 | Shear |
| 4 | MATA-SXZ-04-70 | 547 | 3,692 | 695,696 | Shear |
| 5 | MATA-SXZ-05-70 | 541 | 3,910 | 746,682 | Shear |
| Average | | 581 | 4,137 | 820,919 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear chord modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are attached, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.015 in/min will be used for the best data acquisition. The ultimate strength is calculated using the lower of the maximum load at failure or the load at 5% shear strain.

Ambient Test Condition**Specimens Nominal Dimensions / Strain Gauge Location**

FACING RESEARCHERS

Notes:

- 1) Individual specimen results are shown on Sheets A-98 to A-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-01-70
 Test Date: 3/10/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 681 lbs
 Shear Stress, S_{xz} : 4,968 psi
 Shear Modulus, G_{xz} : 1,028,177 psi

Measured Specimen Dimensions:

Depth, D: 0.503 in
 Notch Length, NH: 0.265 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 548 lbs
 Load @ .002 $\mu\epsilon$: 270 lbs

PICTURE OF SPECIMEN PRE-TEST



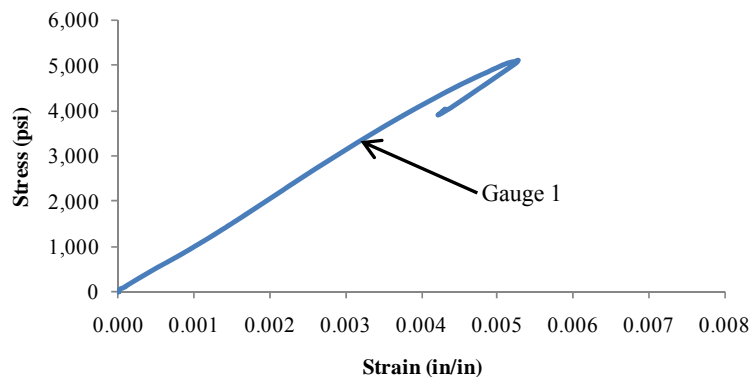
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|-------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 1,028,177 |
| 2 | Lost | Lost | Lost |
| Average | | | 1,028,177 |

Stress-Strain Curve 70_1A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- **Displacement Rate for test 1A was set to 0.05 in/min.

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-02-70
 Test Date: 3/30/11
 Specimen Received: 3/25/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 617 lbs
 Shear Stress, S_{xz} : 4,567 psi
 Shear Modulus, G_{xz} : 930,701 psi

Measured Specimen Dimensions:

Depth, D: 0.503 in
 Notch Length, NH: 0.265 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 568 lbs
 Load @ .002 $\mu\epsilon$: 320 lbs

PICTURE OF SPECIMEN PRE-TEST



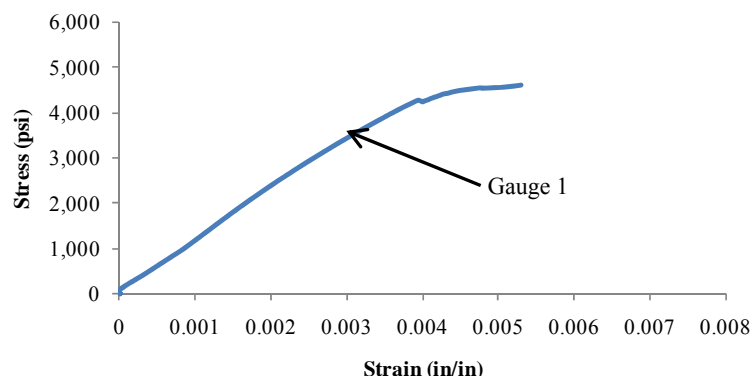
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|-------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 930,701 |
| 2 | Lost | Lost | Lost |
| Average | | | 930,701 |

Stress-Strain Curve 70_2A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- **Displacement Rate for test 2A was set to 0.025 in/min.

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-03-70
 Test Date: 4/01/11
 Specimen Received: 3/25/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 521 lbs
 Shear Stress, S_{xz} : 3,550 psi
 Shear Modulus, G_{xz} : 703,337 psi

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NH: 0.262 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 423 lbs
 Load @ .002 $\mu\epsilon$: 239 lbs

PICTURE OF SPECIMEN PRE-TEST



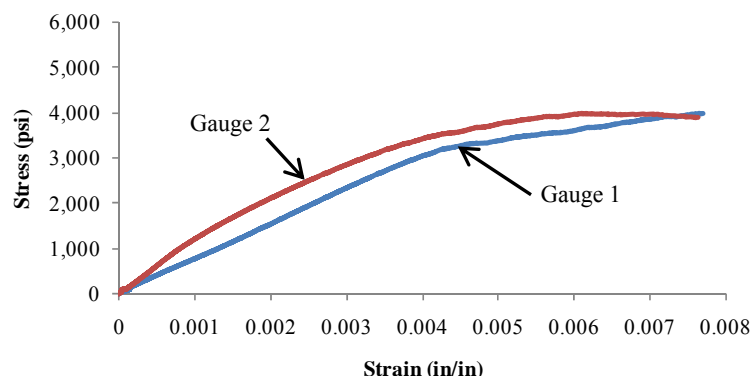
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|-------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 751,382 |
| 2 | Lost | Lost | 655,291 |
| Average | | | 703,337 |

Stress-Strain Curve 70_3A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- **Displacement Rate for test 3A was set to 0.005 in/min.

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-04-70
 Test Date: 4/01/11
 Specimen Received: 3/25/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 547 lbs
 Shear Stress, S_{xz} : 3,692 psi
 Shear Modulus, G_{xz} : 695,696 psi

Measured Specimen Dimensions:

Depth, D: 0.506 in
 Notch Length, NH: 0.257 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 405 lbs
 Load @ .002 $\mu\epsilon$: 224 lbs

PICTURE OF SPECIMEN PRE-TEST



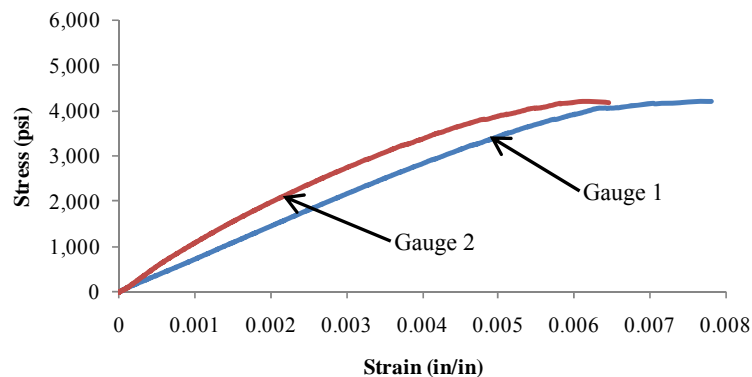
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|-------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 693,013 |
| 2 | Lost | Lost | 698,380 |
| Average | | | 695,696 |

Stress-Strain Curve 70_4A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- **Displacement Rate for test 4A was set to 0.015 in/min.

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-05-70
 Test Date: 4/01/11
 Specimen Received: 3/25/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 541 lbs
 Shear Stress, S_{xz} : 3,910 psi
 Shear Modulus, G_{xz} : 746,682 psi

Measured Specimen Dimensions:

Depth, D: 0.506 in
 Notch Length, NH: 0.257 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 441 lbs
 Load @ .002 $\mu\epsilon$: 247 lbs

PICTURE OF SPECIMEN PRE-TEST



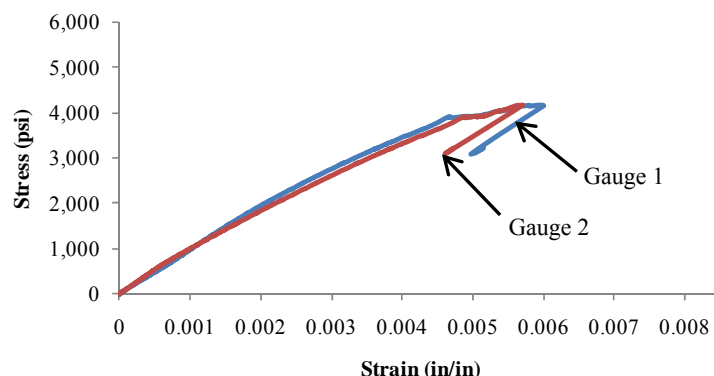
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|-------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 750,708 |
| 2 | Lost | Lost | 742,657 |
| Average | | | 746,682 |

Stress-Strain Curve 70_5A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- **Displacement Rate for test 5A was set to 0.015 in/min.

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

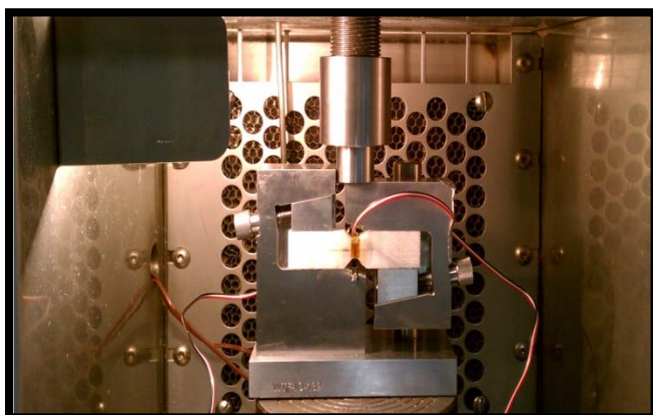
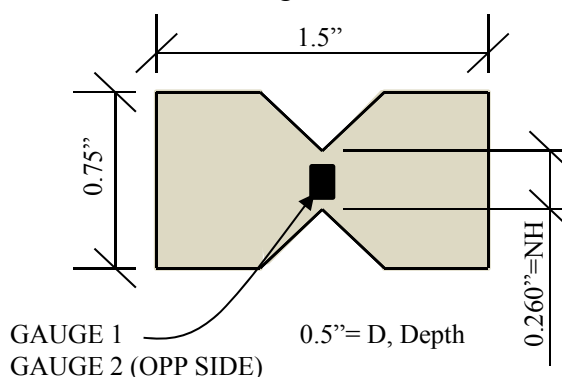
Specimen ID Group: MATA-SXZ-140
 Material: Acceptance Material
 Nominal Temperature: 140°F
 Properties Measured: G_{xz} , S_{xz}
 Average Material Properties (5 Specimens):

| | | |
|----------------------------|---------|-----|
| Ultimate Load, P_{max} : | 368 | lbs |
| Shear Strength, S_{xz} : | 2,853 | psi |
| Shear Modulus, G_{xz} : | 530,676 | psi |

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|-----------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 2 | MATA-SXZ-02-140 | 379 | 2,862 | 546,496 | Shear |
| 4 | MATA-SXZ-04-140 | 371 | 2,846 | 513,880 | Shear |
| 5 | MATA-SXZ-05-140 | 389 | 2,988 | 549,055 | Shear |
| 6 | MATA-SXZ-06-140 | 349 | 2,788 | 517,406 | Shear |
| 7 | MATA-SXZ-07-140 | 352 | 2,782 | 526,545 | Shear |
| Average | | 368 | 2,853 | 530,676 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear chord modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are attached, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.015 in/min will be used for the best data acquisition. The ultimate strength is calculated using the lower of the maximum load at failure or the load at 5% shear strain.

140°F Test Condition**Specimens Nominal Dimensions / Strain Gauge Location****FACING RESEARCHERS****Notes:**

- 1) Individual specimen results are shown on Sheets A-104 to A-108
- 2) Seven specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-02-140
 Test Date: 4/6/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

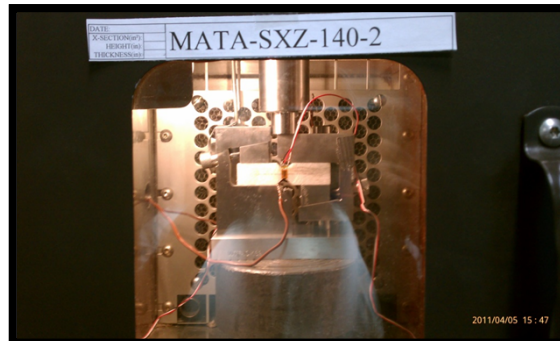
Average Material Properties:

Ultimate Load, P_{max} : 379 lbs
 Shear Stress, S_{xz} : 2,862 psi
 Shear Modulus, G_{xz} : 546,496 psi

Measured Specimen Dimensions:

Depth, D: 0.500 in
 Notch Length, NH: 0.265 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 324 lbs
 Load @ .002 $\mu\epsilon$: 180 lbs

PICTURE OF SPECIMEN PRE-TEST



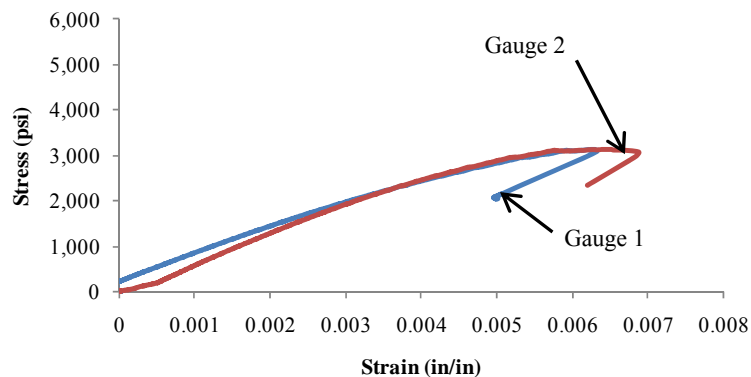
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 499,747 |
| 2 | 0.0040 | 0.0020 | 593,244 |
| Average | | | 546,496 |

Stress-Strain Curve 140_2A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 2A was calculated using the ultimate load

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-04-140
 Test Date: 4/6/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 371 lbs
 Shear Stress, S_{xz} : 2,846 psi
 Shear Modulus, G_{xz} : 513,880 psi

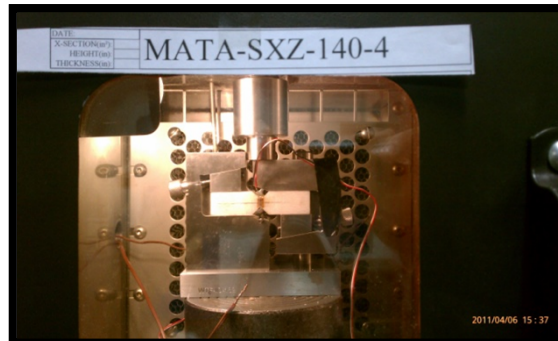
Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NH: 0.262 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 320 lbs
 Load @ .002 $\mu\epsilon$: 186 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 529,960 |
| 2 | 0.0040 | 0.0020 | 497,801 |
| Average | | | 513,880 |

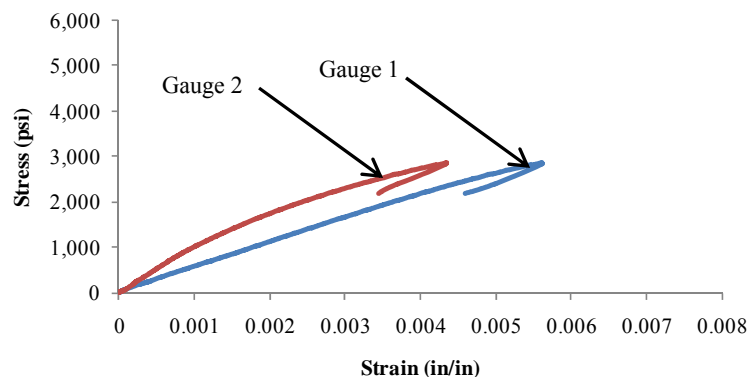
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140_4A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 4A was calculated using the load at 5% shear strain

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-05-140
 Test Date: 4/7/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 389 lbs
 Shear Stress, S_{xz} : 2,988 psi
 Shear Modulus, G_{xz} : 549,055 psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NH: 0.262 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 336 lbs
 Load @ .002 $\mu\epsilon$: 193 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 578,869 |
| 2 | 0.0040 | 0.0020 | 519,240 |
| Average | | | 549,055 |

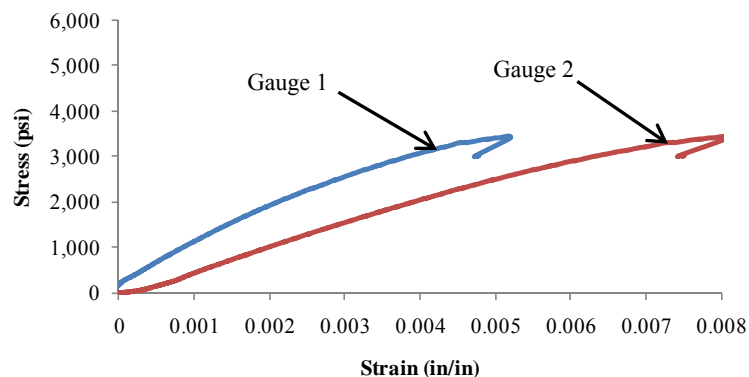
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140_5A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 5A was calculated using the load at 5% shear strain

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-06-140
 Test Date: 4/7/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 349 lbs
 Shear Stress, S_{xz} : 2,788 psi
 Shear Modulus, G_{xz} : 517,406 psi

Measured Specimen Dimensions:

Depth, D: 0.48 in
 Notch Length, NH: 0.261 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 300 lbs
 Load @ .002 $\mu\epsilon$: 171 lbs

PICTURE OF SPECIMEN PRE-TEST



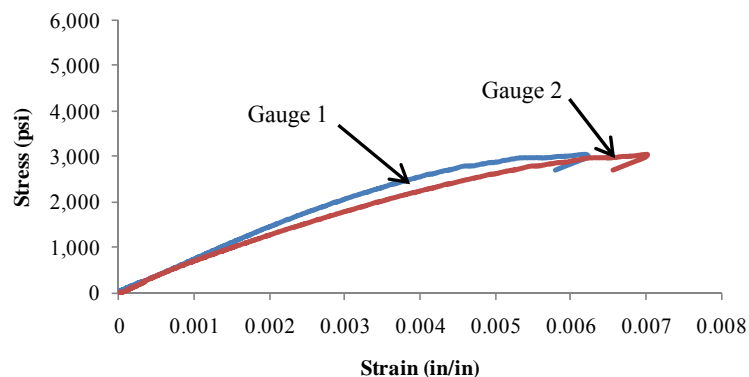
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 552,225 |
| 2 | 0.0040 | 0.0020 | 482,587 |
| Average | | | 517,406 |

Stress-Strain Curve 140_6A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 6A was calculated using the load at 5% shear strain

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MATA-SXZ-07-140
 Test Date: 4/7/11
 Specimen Received: 3/30/11
 Properties Measured: S_{xz} , G_{xz}

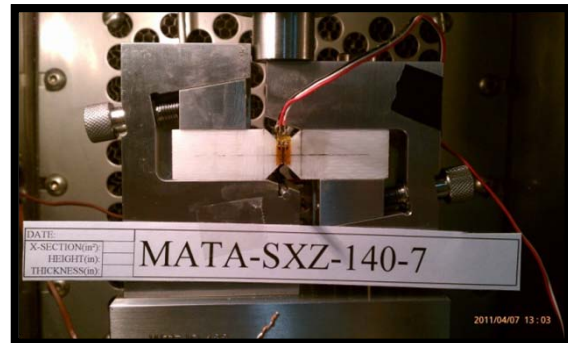
Average Material Properties:

Ultimate Load, P_{max} : 352 lbs
 Shear Stress, S_{xz} : 2,782 psi
 Shear Modulus, G_{xz} : 526,545 psi

Measured Specimen Dimensions:

Depth, D: 0.485 in
 Notch Length, NH: 0.261 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 Load @ .004 $\mu\epsilon$: 300 lbs
 Load @ .002 $\mu\epsilon$: 167 lbs

PICTURE OF SPECIMEN PRE-TEST



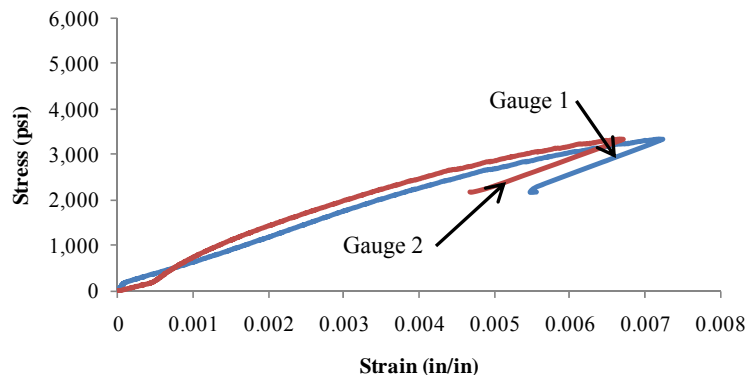
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|--|--|----------------------------------|
| Gauge | Strain @ .004 $\mu\epsilon$ (in/in) | Strain @ .002 $\mu\epsilon$ (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0040 | 0.0020 | 540,329 |
| 2 | 0.0040 | 0.0020 | 512,761 |
| Average | | | 526,545 |

Stress-Strain Curve 140_7A



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-187UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using a strain range of 2000 $\mu\epsilon$ -4000 $\mu\epsilon$
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Ultimate Strength for test 7A was calculated using the load at 5% shear strain

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

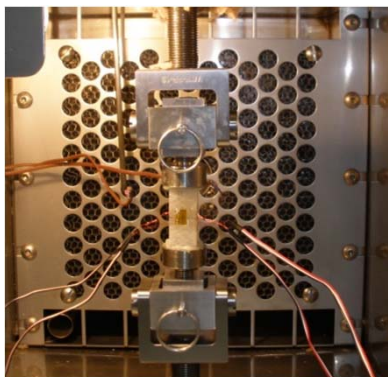
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MATA-OP-N40
 Material: Huntsman Epoxy Resin 8605, DHF
 Nominal Temperature: -40°F
 Properties Measured: ν_{xz}
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1744

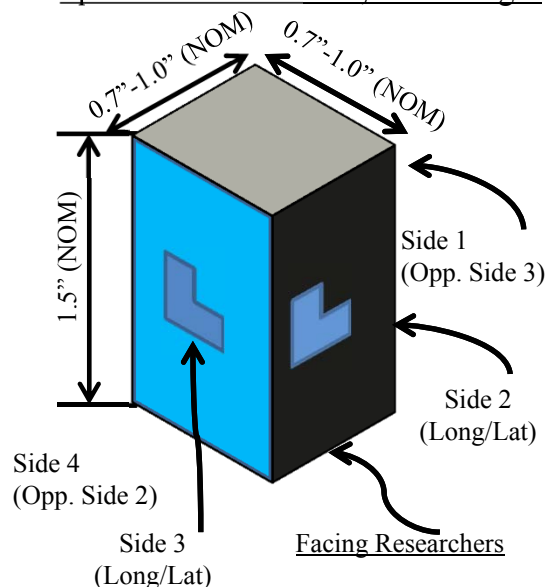
| Sample | Specimen | Max Stress, σ_z (psi) | Failure Mode | Poisson’s Ratio, ν_{xz} |
|----------------|---------------|------------------------------|--------------|-----------------------------|
| 1 | MATA-OP-N40-1 | 2,258 | Rupture | 0.1445 |
| 2 | MATA-OP-N40-2 | 2,562 | Rupture | 0.2286 |
| 3 | MATA-OP-N40-4 | 1,462 | Bondline | 0.1417 |
| 4 | MATA-OP-N40-7 | 2,032 | Rupture | 0.1703 |
| 5 | MATA-OP-N40-8 | 2,552 | Rupture | 0.1868 |
| Average | | 2,173 | | 0.174 |

Test Description and Notes (This Set Only):

The out-of-plane Poisson Ratio Test is conducted using a modified version of ASTM D7291/ D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The first six specimens tested were 0.7”x0.7”x1.5” long blocks. The seventh and eighth tests were performed on specimens that were cut from an in-plane compression specimen. These specimens were machined in the laboratory to dimensions of 1.0”x1.0”x1.5” long blocks. The test is performed in the same manner as the out-of-plane tension test using the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will measure Poisson’s ratio on adjacent sides of the specimen.

-40°F Test Condition**Notes:**

- 1) Reference A-110 thru A-114 for individual specimen data.
- 2) 8 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 3mm from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 3mm from the epoxied specimen at the base.

Specimens Dimensions, Strain Gages

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-N40-1**
 Test Date: 12/17/2010
 Specimen Received: 11/19/2010
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Stress, σ_z : 2,258 psi
 Poisson's Ratio, v_{xz} : 0.1445

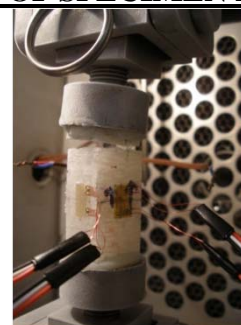
Measured/Nominal Specimen Dimensions:

Length, L: 1.5 (1.500) in
 Width, W: 0.7150 (0.700) in
 Thickness, T: 0.6500 (0.700) in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,129 psi
 20% Max Stress: 452 psi

PICTURE OF SPECIMEN PRE-TEST



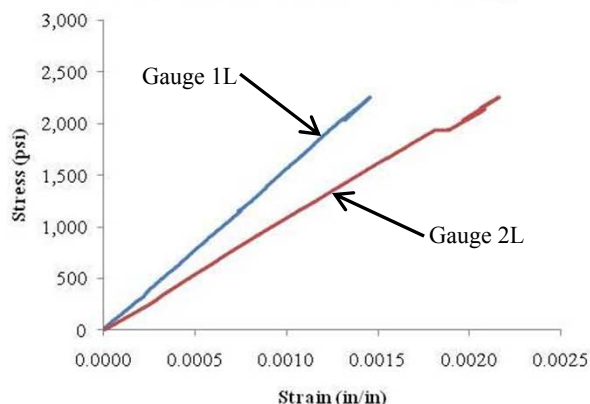
PICTURE OF SPECIMEN POST-TEST



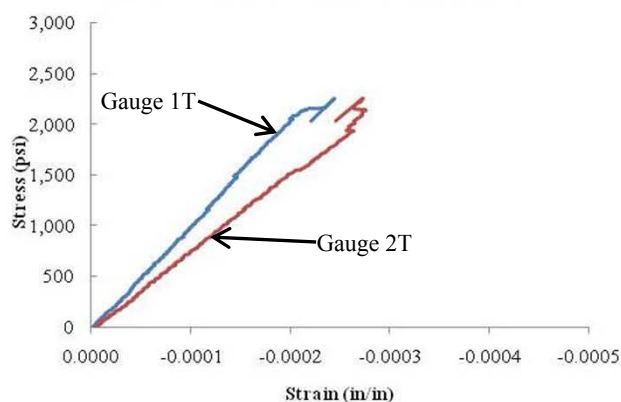
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|----------------------------|----------------------------|----------------|----------------------------|----------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | (in/in) | (in/in) | |
| 1L | 0.000728 | 0.000285 | 1T | -0.000114 | -0.000047 | 0.1506 |
| 2L | 0.001035 | 0.000420 | 2T | -0.000148 | -0.000063 | 0.1385 |
| Average | | | | | | 0.1445 |

Stress-Strain Curve 1A, Long



Stress-Strain Curve 1A, Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-N40-2**
 Test Date: 12/17/2010
 Specimen Received: 11/19/2010
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Stress, σ_z : 2,562 psi
 Poisson's Ratio, v_{xz} : 0.2286

Measured/Nominal Specimen Dimensions:

Length, L: 1.5 (1.500) in
 Width, W: 0.6750 (0.700) in
 Thickness, T: 0.6860 (0.700) in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,281 psi
 20% Max Stress: 512 psi

PICTURE OF SPECIMEN PRE-TEST



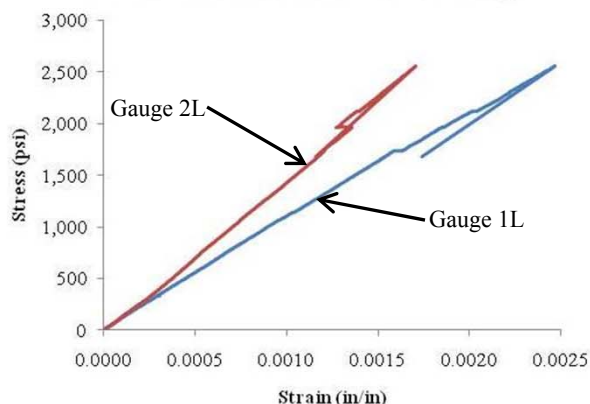
PICTURE OF SPECIMEN POST-TEST



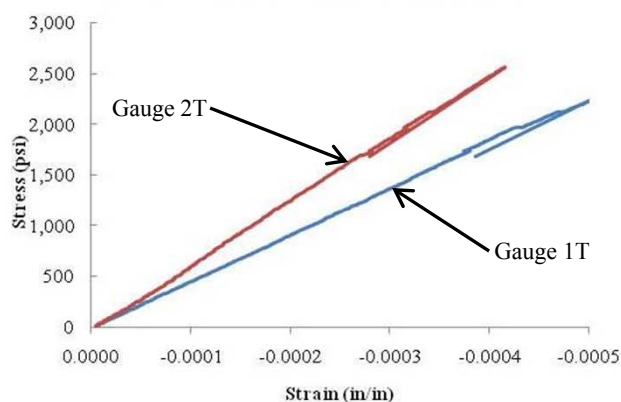
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | |
|---------------------|----------------------------|----------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Poisson's Ratio |
| | (in/in) | (in/in) | | (in/in) | (in/in) | v_{xz} |
| 1L | 0.001172 | 0.000461 | 1T | -0.000282 | -0.000115 | 0.2341 |
| 2L | 0.000898 | 0.000385 | 2T | -0.000204 | -0.000090 | 0.2232 |
| Average | | | | | | 0.2286 |

Stress-Strain Curve 2A, Long



Stress-Strain Curve 2A, Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-N40-4**
 Test Date: 12/17/2010
 Specimen Received: 11/19/2010
 Properties Measured: ν_{xz}

Average Material Properties:

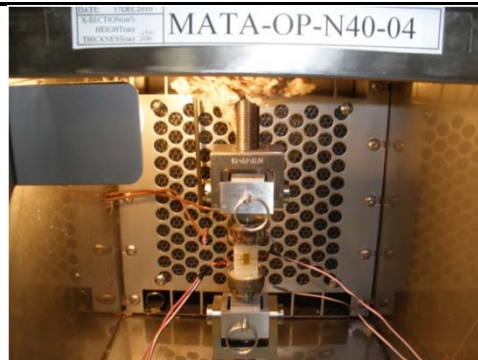
Maximum Stress, σ_z : 1,462 psi
 Poisson's Ratio, ν_{xz} : 0.1417

Measured/Nominal Specimen Dimensions:

Length, L: 1.5 (1.500) in
 Width, W: 0.6981 (0.700) in
 Thickness, T: 0.7489 (0.700) in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Stress: 731 psi
 20% Max Stress: 292 psi

PICTURE OF SPECIMEN PRE-TEST



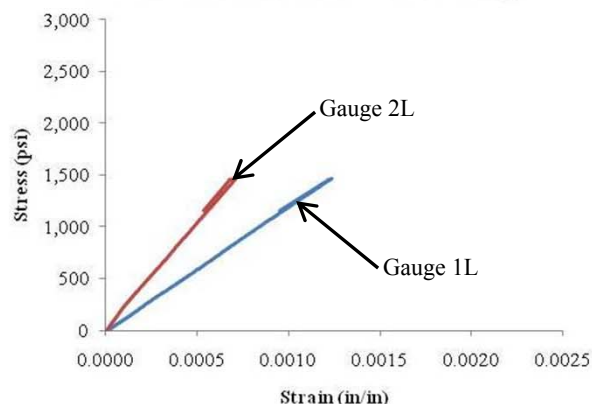
PICTURE OF SPECIMEN POST-TEST



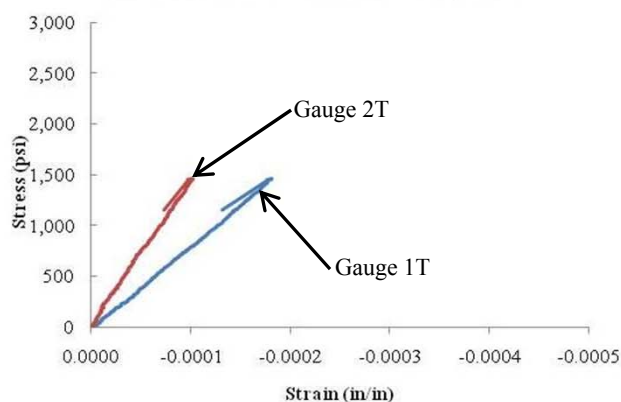
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio ν_{xz} |
|---------------------|----------------------------|----------------------------|----------------|----------------------------|----------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | (in/in) | (in/in) | |
| 1L | 0.000618 | 0.000247 | 1T | -0.000092 | -0.000039 | 0.1422 |
| 2L | 0.000349 | 0.000129 | 2T | -0.000048 | -0.000017 | 0.1413 |
| Average | | | | | | 0.1417 |

Stress-Strain Curve 4A, Long



Stress-Strain Curve 4A, Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-N40-7**
 Test Date: 12/21/2010
 Specimen Received: 11/19/2010
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Stress, σ_z : 2,032 psi
 Poisson's Ratio, v_{xz} : 0.1703

Measured/Nominal Specimen Dimensions:

Length, L: 1.5 (1.500) in
 Width, W: 1.000 (1.000) in
 Thickness, T: 1.000 (1.000) in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,016 psi
 20% Max Stress: 406 psi

PICTURE OF SPECIMEN PRE-TEST



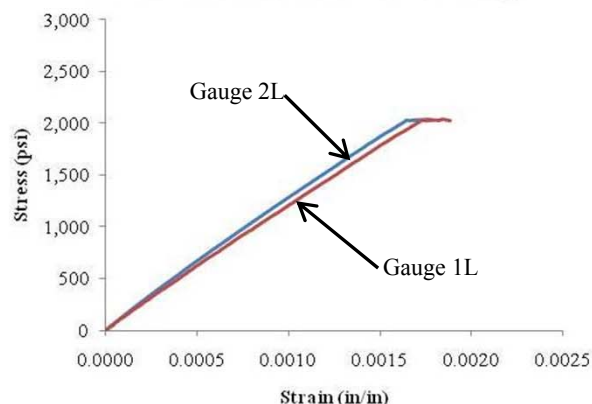
PICTURE OF SPECIMEN POST-TEST



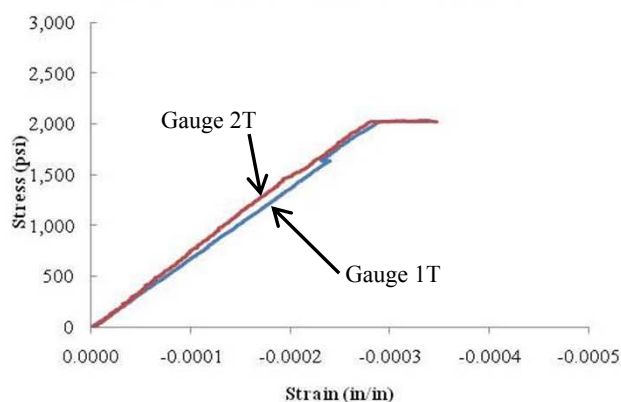
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|----------------------------|----------------------------|----------------|----------------------------|----------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | (in/in) | (in/in) | |
| 1L | 0.000778 | 0.000292 | 1T | -0.000150 | -0.000060 | 0.1842 |
| 2L | 0.000833 | 0.000317 | 2T | -0.000135 | -0.000054 | 0.1563 |
| Average | | | | | | 0.1703 |

Stress-Strain Curve 7A, Long



Stress-Strain Curve 7A, Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-N40-8**
 Test Date: 12/21/2010
 Specimen Received: 11/19/2010
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Stress, σ_z : 2,552 psi
 Poisson's Ratio, v_{xz} : 0.1868

Measured/Nominal Specimen Dimensions:

Length, L: 1.5 (1.500) in
 Width, W: 1.000 (1.000) in
 Thickness, T: 1.000 (1.000) in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,276 psi
 20% Max Stress: 510 psi

PICTURE OF SPECIMEN PRE-TEST



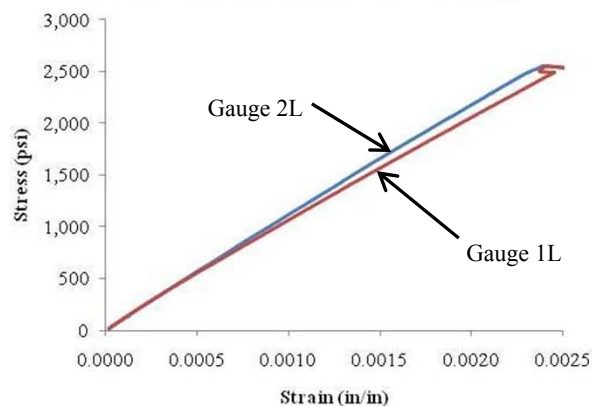
PICTURE OF SPECIMEN POST-TEST



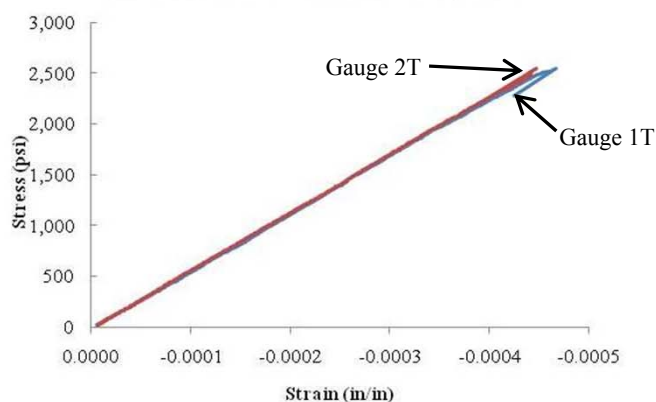
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | |
|---------------------|----------------------------|----------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Poisson's Ratio |
| | (in/in) | (in/in) | | (in/in) | (in/in) | v_{xz} |
| 1L | 0.001143 | 0.000442 | 1T | -0.000229 | -0.000094 | 0.1923 |
| 2L | 0.001203 | 0.000451 | 2T | -0.000227 | -0.000090 | 0.1814 |
| Average | | | | | | 0.1868 |

Stress-Strain Curve 8A, Long



Stress-Strain Curve 8A, Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

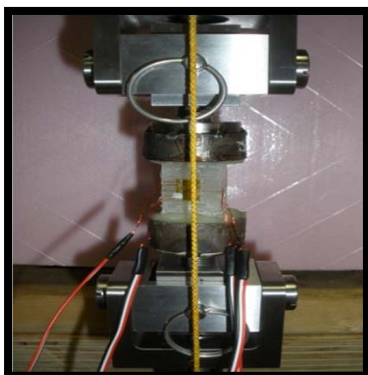
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MATA-OP-70**
 Material: **Huntsman Epoxy Resin 8605, DHF**
 Nominal Temperature: **70°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s ratio, ν_{xz} : **0.1770**
 Maximum Load, P_z : **1,093 lbs**

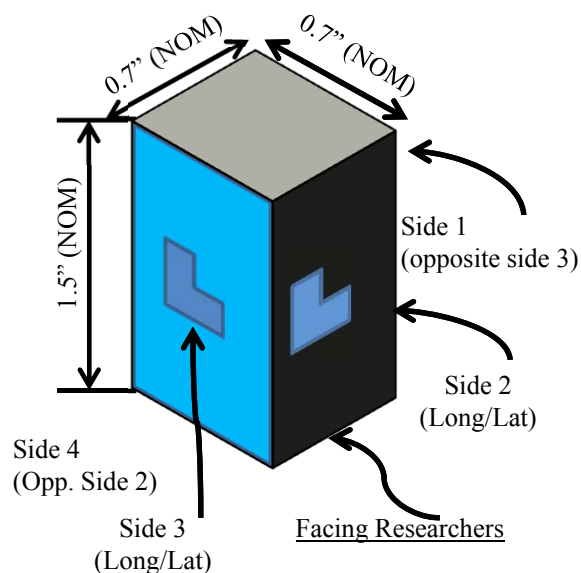
| Sample | Specimen | Max Load, P_z (lb) | Failure Mode | Poisson’s Ratio ν_{xz} |
|----------------|--------------|----------------------|--------------|-------------------------------|
| 1 | MATA-OP-1-70 | 951 | Bondline | 0.2062 |
| 2 | MATA-OP-2-70 | 1,169 | Rupture | 0.2119 |
| 3 | MATA-OP-3-70 | 1,181 | Bondline | 0.1553 |
| 4 | MATA-OP-4-70 | 1,068 | Bondline | 0.1199 |
| 5 | MATA-OP-5-70 | 1,096 | Rupture | 0.1915 |
| Average | | 1,093 | | 0.1770 |

Test Description:

The out-of-plane Poisson Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The blocks used to perform the acceptance testing were 0.7”x0.7”x1.5” long. The test is performed in the same manner as the out-of-plane tension test. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine Poisson’s ratio on adjacent sides of the specimen.

Ambient Temp. Test Cond.**Notes:**

- 1) Reference A-116 thru A-120 for individual specimen data.
- 2) Bondline failure refers to ASTM failure of less than 3 mm from the epoxied specimen at the base.
- 3) Rupture failure refers to ASTM failure greater than 3mm from the epoxied specimen at the base.

Specimens Dimensions, Strain Gages

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-1-70**
 Test Date: 10/27/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: v_{xz}

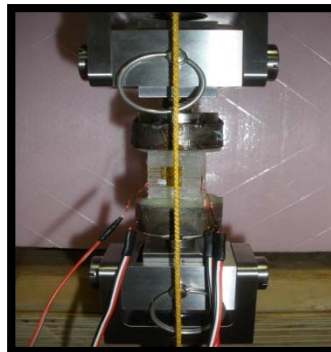
Average Material Properties:

Maximum Load, P_z : 951 lbs
 Poisson's ratio, v_{xz} : 0.1977

Measured/Theoretical Specimen Dimensions:

Length, L: 1.43 (1.50) in
 Width, W: 0.6971 (0.700) in
 Thickness, T: 0.6979 (0.700) in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 475 lb
 20% Max Load: 190 lb

PICTURE OF SPECIMEN PRE-TEST



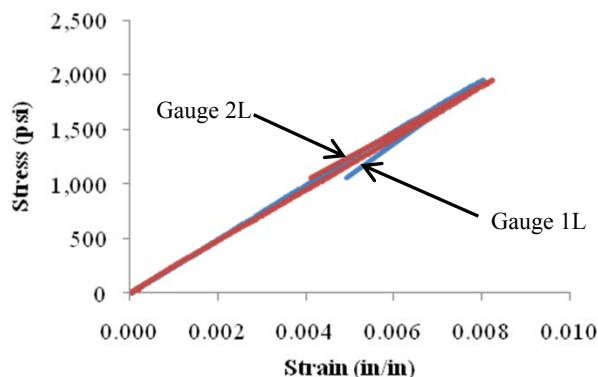
PICTURE OF SPECIMEN POST-TEST



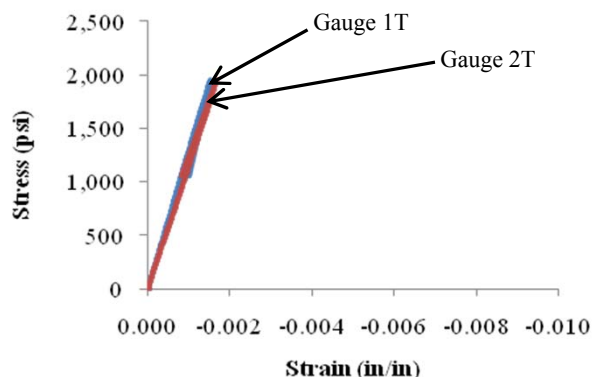
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.0040 | 0.0016 | 1T | -0.0008 | -0.0003 | 0.1892 |
| 2L | 0.0041 | 0.0016 | 2T | -0.0009 | -0.0003 | 0.2062 |
| Average | | | | | | 0.1977 |

Stress-Strain Curve 1A Long.



Stress-Strain Curve 1A Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-2-70**
 Test Date: 10/27/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: ν_{xz}

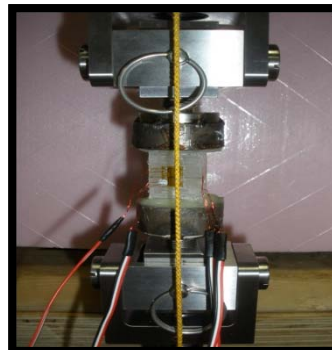
Average Material Properties:

Maximum Load, P_z : 1,169 lbs
 Poisson's ratio, ν_{xz} : 0.1586

Measured/Theoretical Specimen Dimensions:

Length, L: 1.43 (1.50) in
 Width, W: 0.7131 (0.700) in
 Thickness, T: 0.7128 (0.700) in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 585 lb
 20% Max Load: 234 lb

PICTURE OF SPECIMEN PRE-TEST



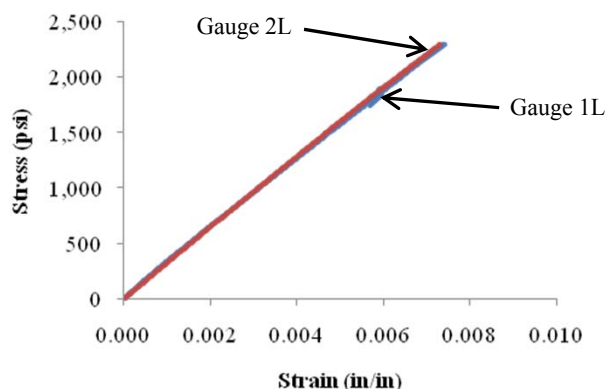
PICTURE OF SPECIMEN POST-TEST



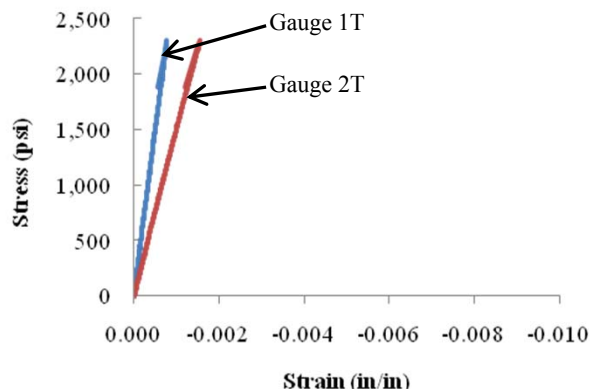
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio |
|--------------------|-------------------------------|-------------------------------|---------------|-----------------------|-----------------------|-----------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Gauge | Strain @ 50% Max Load | Strain @ 20% Max Load | |
| | | | | (in/in) | (in/in) | ν_{xz} |
| 1L | 0.0036 | 0.0014 | 1T | -0.0004 | -0.0001 | 0.1053 |
| 2L | 0.0036 | 0.0014 | 2T | -0.0008 | -0.0003 | 0.2119 |
| Average | | | | | | 0.1586 |

Stress-Strain Curve 2A Long.



Stress-Strain Curve 2A Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-3-70**
 Test Date: 10/27/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: v_{xz}

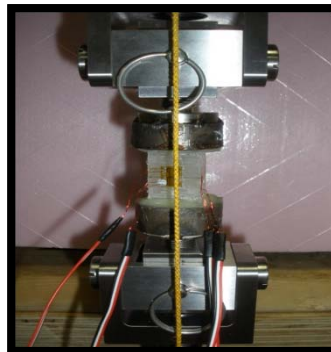
Average Material Properties:

Maximum Load, P_z : 1,181 lbs
 Poisson's ratio, v_{xz} : 0.1864

Measured/Theoretical Specimen Dimensions:

Length, L: 1.44 (1.50) in
 Width, W: 0.7067 (0.700) in
 Thickness, T: 0.6661 (0.700) in
 Laboratory Temperature: 68°F
 Failure Mode: None
 50% Max Load: 590 lb
 20% Max Load: 236 lb

PICTURE OF SPECIMEN PRE-TEST



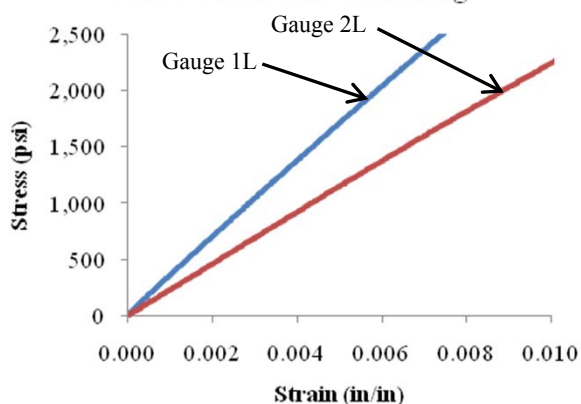
PICTURE OF SPECIMEN POST-TEST



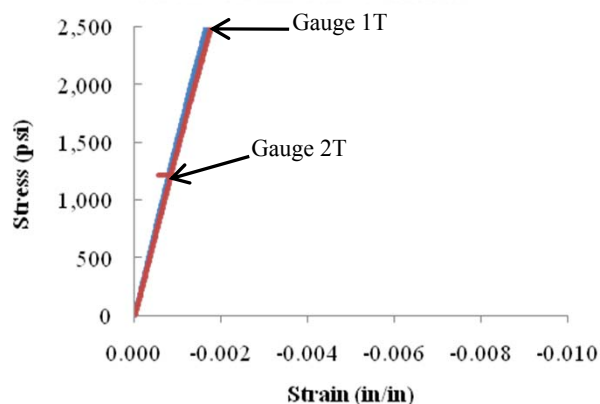
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio |
|--------------------|-------------------------------|-------------------------------|---------------|-------------------------------|-------------------------------|-----------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| | | | | | | n_{xz} |
| 1L | 0.0036 | 0.0014 | 1T | -0.0008 | -0.0003 | 0.2175 |
| 2L | 0.0055 | 0.0022 | 2T | -0.0009 | -0.0004 | 0.1553 |
| Average | | | | | | 0.1864 |

Stress-Strain Curve 3A Long.



Stress-Strain Curve 3A Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-4-70**
 Test Date: 10/28/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: v_{xz}

Average Material Properties:

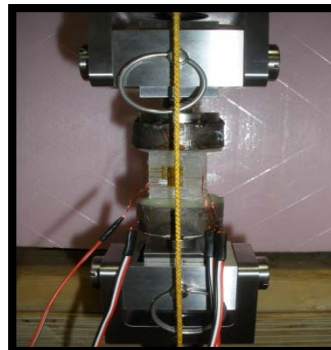
Maximum Load, P_z : 1,068 lbs
 Poisson's ratio, v_{xz} : 0.1392

Measured/Theoretical Specimen Dimensions:

Length, L: 1.44 (1.50) in
 Width, W: 0.7167(0.700) in
 Thickness, T: 0.7169 (0.700) in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 214 lb
 20% Max Load: 534 lb

PICTURE OF SPECIMEN PRE-TEST



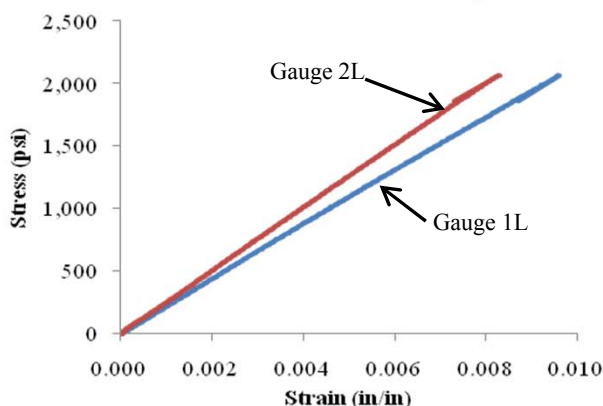
PICTURE OF SPECIMEN POST-TEST



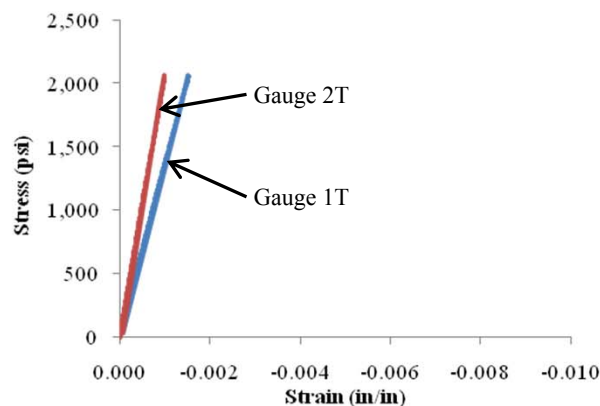
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio |
|--------------------|-------------------------------|-------------------------------|---------------|-------------------------------|-------------------------------|-----------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.0047 | 0.0019 | 0.0016582 | -0.0007 | -0.0003 | 0.1585 |
| 2L | 0.0041 | 0.0019 | 0.0016582 | -0.0005 | -0.0002 | 0.1199 |
| Average | | | | | | 0.1392 |

Stress-Strain Curve 4A Long.



Stress-Strain Curve 4A Lat.



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-5-70**
 Test Date: 10/28/2010
 Specimen Rcvd.: 9/27/2010
 Properties Measured: v_{xz}

Average Material Properties:

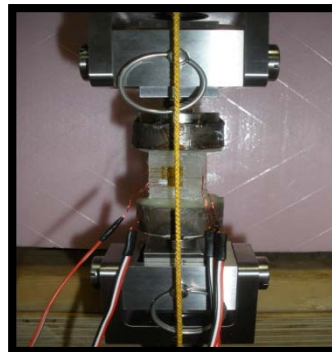
Maximum Load, P_z : 1,096 lbs
 Poisson's ratio, v_{xz} : 0.1760

Measured/Theoretical Specimen Dimensions:

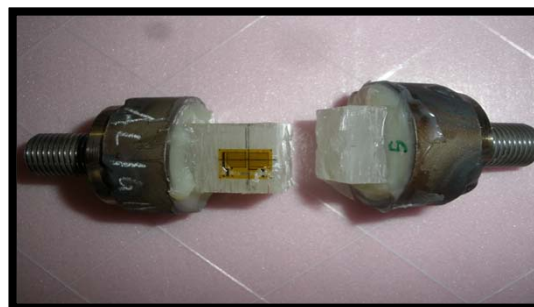
Length, L: 1.45 (1.50) in
 Width, W: 0.7021 (0.700) in
 Thickness, T: 0.6762 (0.700) in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 219 lb
 20% Max Load: 548 lb

PICTURE OF SPECIMEN PRE-TEST



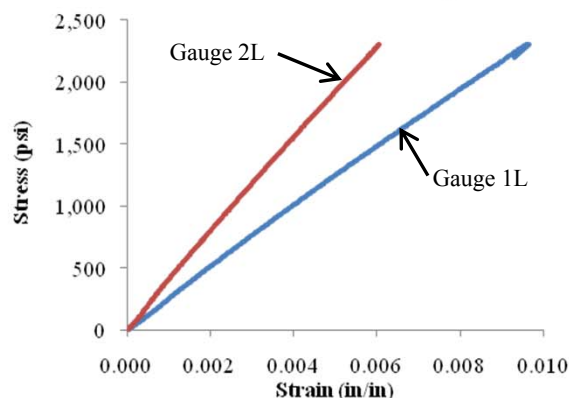
PICTURE OF SPECIMEN POST-TEST



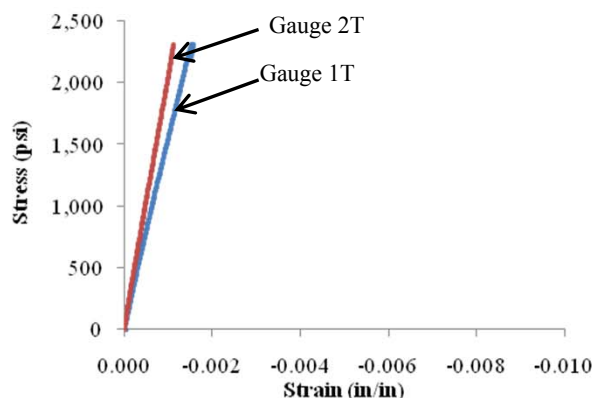
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | |
|--------------------|-------------------------------|-------------------------------|---------------|-----------------------|-----------------------|-----------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Gauge | Strain @ 50% Max Load | Strain @ 20% Max Load | Poisson's Ratio |
| | | | | (in/in) | (in/in) | n_{xz} |
| 1L | 0.0046 | 0.0018 | 1T | -0.0007 | -0.0003 | 0.1604 |
| 2L | 0.0029 | 0.0011 | 2T | -0.0006 | -0.0002 | 0.1915 |
| Average | | | | | | 0.1760 |

Stress-Strain Curve 5A Long.



Stress-Strain Curve 5A Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

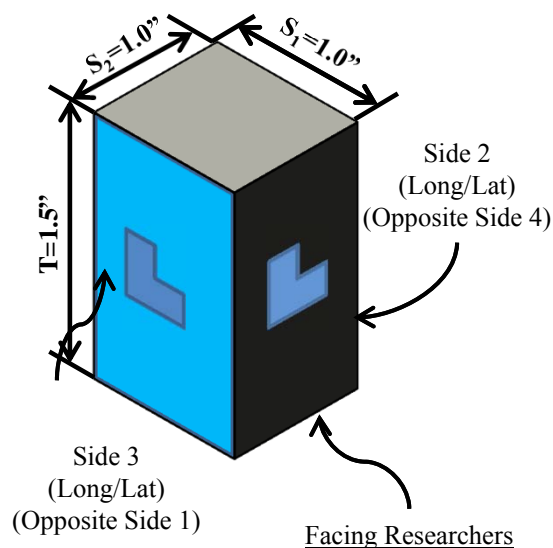
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MATA-OP-140**
 Material: **Huntsman Epoxies SC-15, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.1786**
 Maximum Load, P_z : **791 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|---------------|-------------------------|--------------------------------|--------------|
| 1 | MATA-OP-140-1 | 1,005 | 0.2223 | Rupture |
| 2 | MATA-OP-140-2 | 713 | 0.1659 | Rupture |
| 3 | MATA-OP-140-3 | 703 | 0.1624 | Rupture |
| 4 | MATA-OP-140-4 | 745 | 0.1529 | Rupture |
| 5 | MATA-OP-140-5 | 787 | 0.1894 | Rupture |
| Average | | 791 | 0.1786 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Test Condition**Specimens Nominal Dimensions,
Strain Gauge Locations****Notes:**

- 1) Reference A-122 thru A-126 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-1-140**
 Test Date: 5/4/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

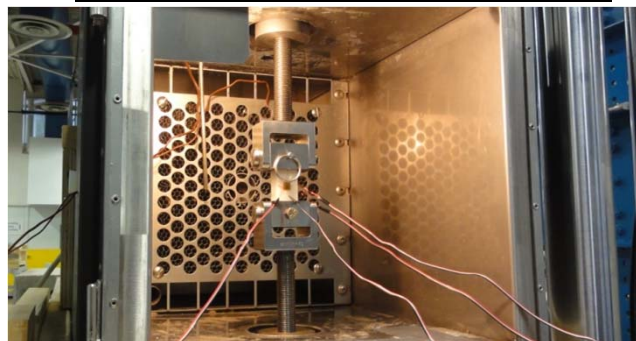
Maximum Load, P_z : 1,005 lbs
 Poisson's Ratio, v_{xz} : 0.2223

Measured Specimen Dimensions:

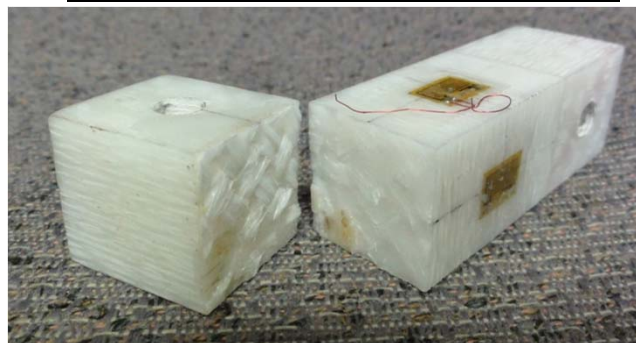
Thickness: 1.375 in
 Side 1: 0.853 in
 Side 2: 0.849 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 503 lbs
 20% Max Load: 201 lbs

PICTURE OF SPECIMEN PRE-TEST

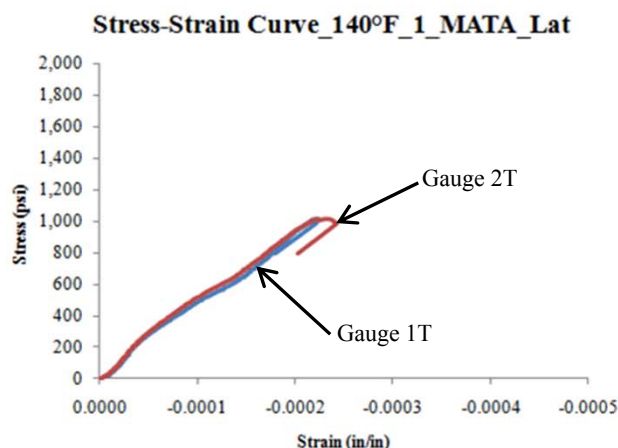
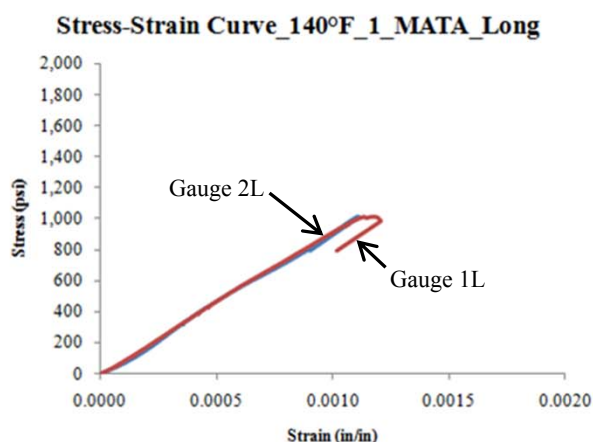


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.000544 | 0.000248 | 1T | -0.000107 | -0.000035 | 0.2416 |
| 2L | 0.000544 | 0.000233 | 2T | -0.000097 | -0.000034 | 0.2031 |
| Average | | | | | | 0.2223 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-2-140**
 Test Date: 5/4/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

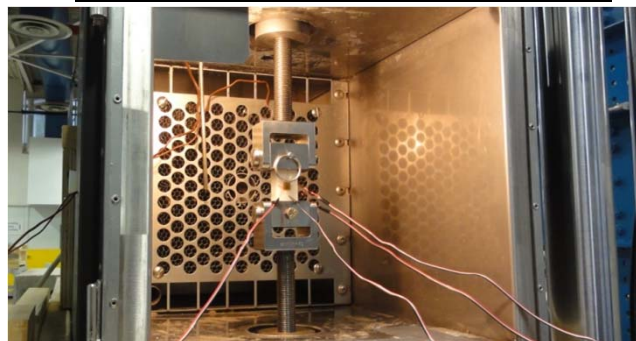
Maximum Load, P_z : 713 lbs
 Poisson's Ratio, v_{xz} : 0.1659

Measured Specimen Dimensions:

Thickness: 1.300 in
 Side 1: 0.810 in
 Side 2: 0.820 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 356 lbs
 20% Max Load: 143 lbs

PICTURE OF SPECIMEN PRE-TEST

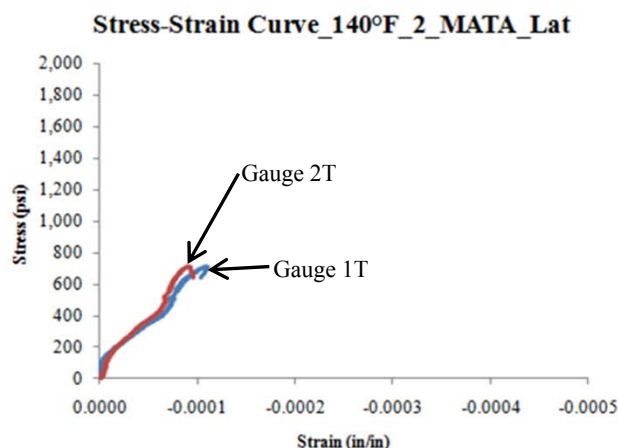
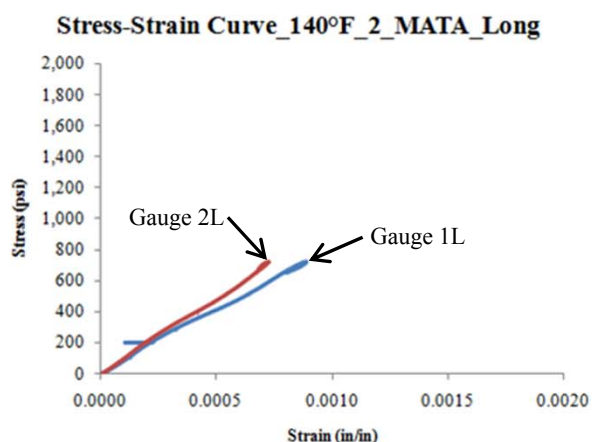


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.000426 | 0.000162 | 1T | -0.000052 | -0.000006 | 0.1754 |
| 2L | 0.000369 | 0.000142 | 2T | -0.000045 | -0.000010 | 0.1564 |
| Average | | | | | | 0.1659 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-3-140**
 Test Date: 5/5/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

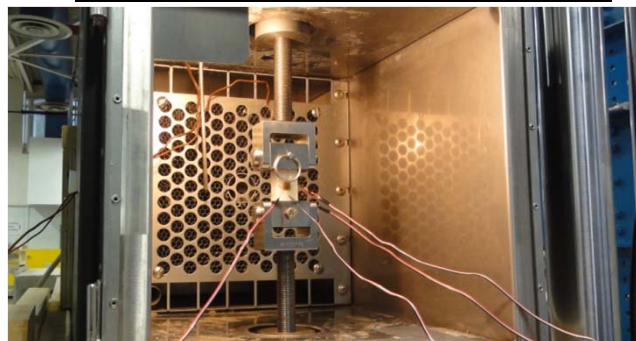
Maximum Load, P_z : 703 lbs
 Poisson's Ratio, v_{xz} : 0.1624

Measured Specimen Dimensions:

Thickness: 1.330 in
 Side 1: 0.817 in
 Side 2: 0.817 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 352 lbs
 20% Max Load: 141 lbs

PICTURE OF SPECIMEN PRE-TEST

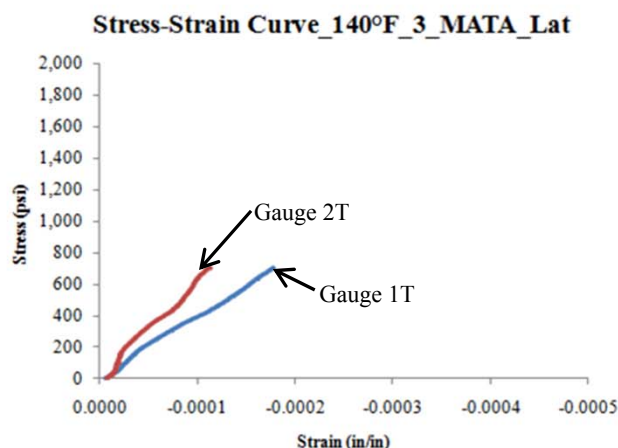
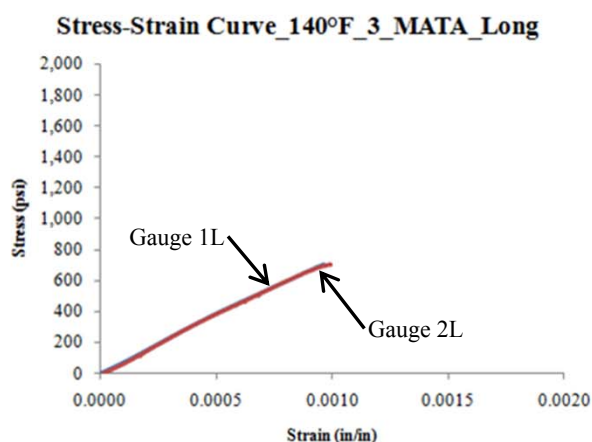


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.000455 | 0.000190 | 1T | -0.000086 | -0.000034 | 0.1993 |
| 2L | 0.000458 | 0.000196 | 2T | -0.000054 | -0.000021 | 0.1256 |
| Average | | | | | | 0.1624 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-4-140**
 Test Date: 5/5/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

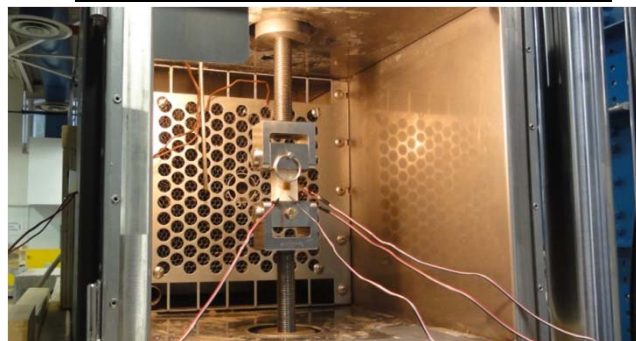
Maximum Load, P_z : 745 lbs
 Poisson's Ratio, v_{xz} : 0.1529

Measured Specimen Dimensions:

Thickness: 1.281 in
 Side 1: 0.859 in
 Side 2: 0.857 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 373 lbs
 20% Max Load: 149 lbs

PICTURE OF SPECIMEN PRE-TEST

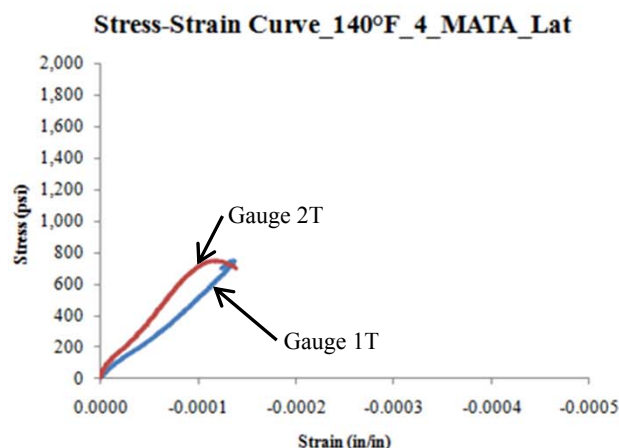
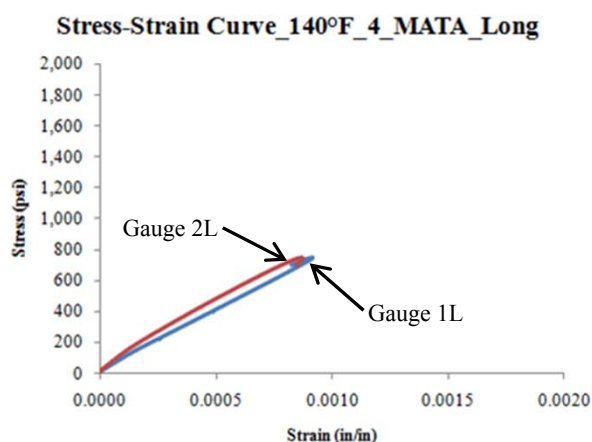


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.000450 | 0.000156 | 1T | -0.000077 | -0.000028 | 0.1661 |
| 2L | 0.000369 | 0.000117 | 2T | -0.000051 | -0.000016 | 0.1397 |
| Average | | | | | | 0.1529 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MATA-OP-5-140**
 Test Date: 5/5/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

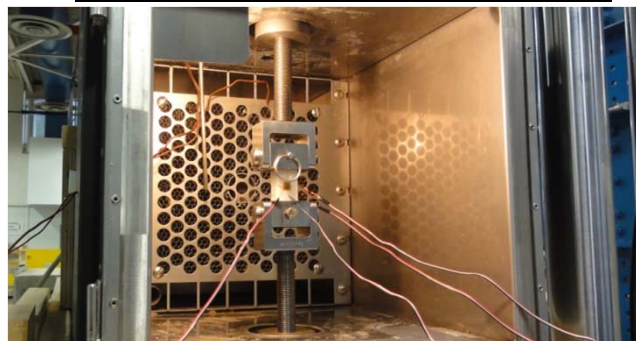
Average Material Properties:

Maximum Load, P_z : 787 lbs
 Poisson's Ratio, v_{xz} : 0.1894

Measured Specimen Dimensions:

Thickness: 1.313 in
 Side 1: 0.861 in
 Side 2: 0.857 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 394 lbs
 20% Max Load: 157 lbs

PICTURE OF SPECIMEN PRE-TEST

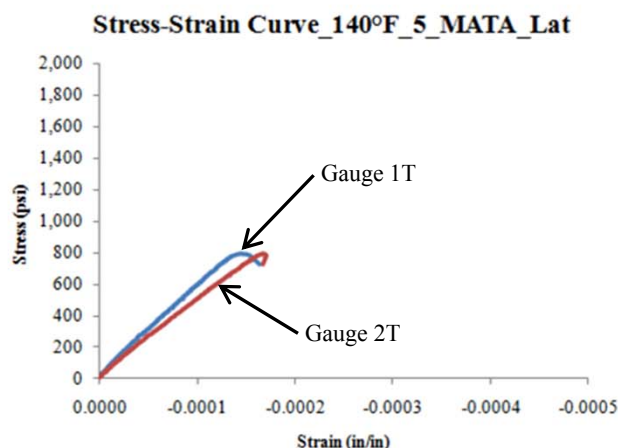
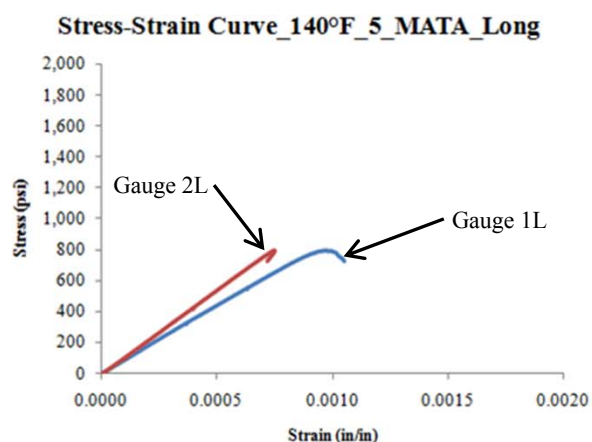


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.000450 | 0.000181 | 1T | -0.000064 | -0.000022 | 0.1563 |
| 2L | 0.000374 | 0.000154 | 2T | -0.000077 | -0.000028 | 0.2225 |
| Average | | | | | | 0.1894 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX B

MATERIAL 1-FY08 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TX-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: N40°F

Properties Measured: ST_x , E_x , ν_{xy}

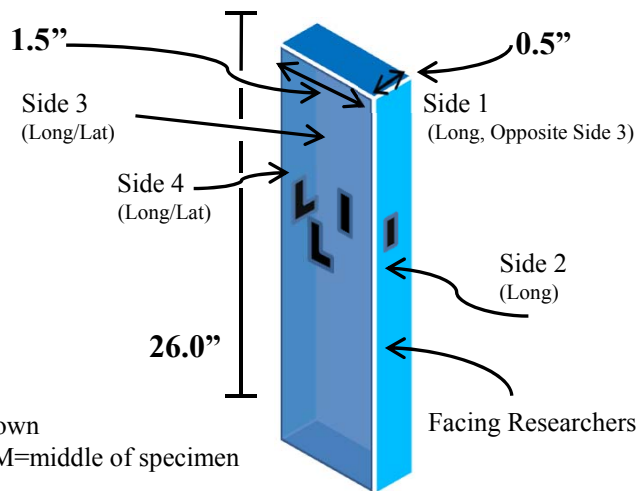
Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 33,887 | lbs |
| Tensile Strength, ST_x : | 51,720 | psi |
| Tensile Modulus, E_x : | 2,339,400 | psi |
| Ultimate Strain, ϵ_x : | 0.0217 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2503 | |

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT1-TX-1-N40-FY08 | 33,830 | 51,289 | 2,413,374 | 0.0213 | 0.2588 | DGM |
| 2 | MAT1-TX-2-N40-FY08 | 32,817 | 51,607 | 2,472,116 | 0.0209 | 0.2227 | DGM |
| 3 | MAT1-TX-3-N40-FY08 | 32,381 | 50,898 | 2,348,168 | 0.0217 | 0.2200 | DGM |
| 4 | MAT1-TX-4-N40-FY08 | 37,447 | 52,520 | 2,139,112 | 0.0246 | 0.2712 | DGM |
| 5 | MAT1-TX-5-N40-FY08 | 32,962 | 52,287 | 2,624,229 | 0.0199 | 0.2786 | DGM |
| Average | | 33,887 | 51,720 | 2,399,400 | 0.0217 | 0.2503 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See B-2 to B-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-N40-FY08**
 Test Date: 2/15/2010
 Specimen Received: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 33,830 lbs
 Tension Stress, ST_x : 51,289 psi
 Tensile Modulus, E_x : 2,413,374 psi
 Ultimate Strain, ϵ_x : 0.0213 in/in
 Poisson's Ratio, v_{xy} : 0.2588

Measured/Nominal Specimen Dimensions:

Width, W: 1.351(1.50) in
 Thickness, H: 0.488(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 6,766 lbs
 50% Max Load: 16,915 lbs

PICTURE OF SPECIMEN PRE-TEST



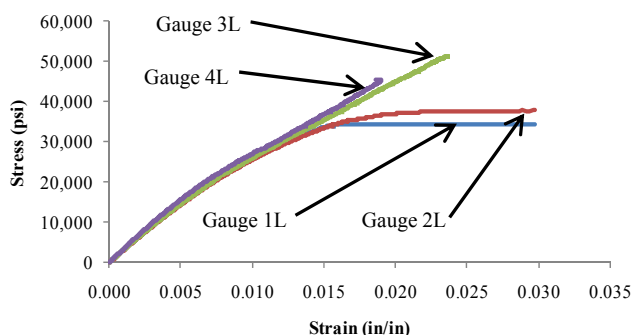
PICTURE OF SPECIMEN POST-TEST



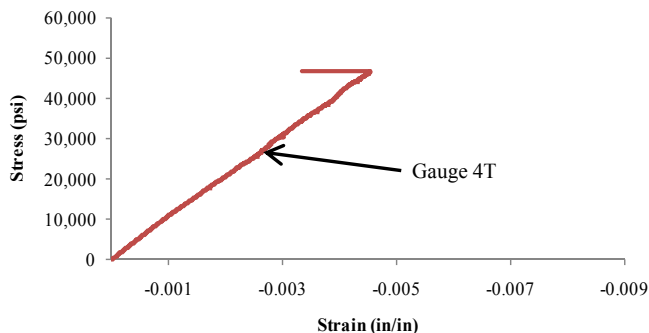
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0098 | 0.0034 | 2,384,020 | | | | |
| 2L (CBW) | 0.0100 | 0.0035 | 2,352,569 | | | | |
| 3L | 0.0098 | 0.0034 | 2,401,935 | | | | |
| 4L | 0.0093 | 0.0031 | 2,514,972 | 4T | -0.0025 | -0.0009 | 0.25884 |
| Average | | | 2,413,374 | | | | |

Stress-Strain Curve N40_1, Long.



Stress-Strain Curve N40_1, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-2-N40-FY08**
 Test Date: 2/15/2010
 Specimen Received : 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 32,817 lbs
 Tension Stress, ST_x : 51,607 psi
 Tensile Modulus, E_x : 2,472,116 psi
 Ultimate Strain, ϵ_x : 0.0209 in/in
 Poisson's Ratio, v_{xy} : 0.2227

Measured/Nominal Specimen Dimensions:

Width, W: 1.380(1.50) in
 Thickness, H: 0.461(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 6,563 lbs
 50% Max Load: 16,408 lbs

PICTURE OF SPECIMEN PRE-TEST



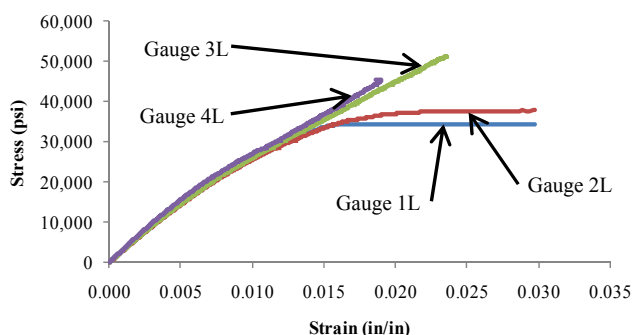
PICTURE OF SPECIMEN POST-TEST



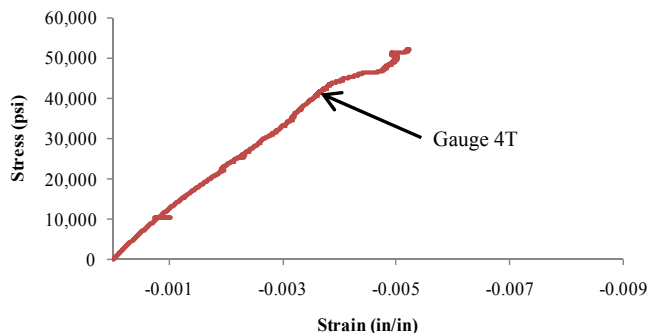
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0091 | 0.0030 | 2,603,776 | | | | |
| 2L (CBW) | 0.0095 | 0.0035 | 2,612,838 | | | | |
| 3L | 0.0098 | 0.0034 | 2,442,863 | | | | |
| 4L | 0.0102 | 0.0035 | 2,332,696 | 4T | -0.0023 | -0.0008 | 0.222678 |
| Average | | | 2,498,043 | | | | |

Stress-Strain Curve N40_1, Long.



Stress-Strain Curve N40_2, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-3-N40-FY08**
 Test Date: 2/16/2010
 Specimen Received: 2/10/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 32,381 lbs
 Tension Stress, ST_x : 50,898 psi
 Tensile Modulus, E_x : 2,348,168 psi
 Ultimate Strain, ϵ_x : 0.0217 in/in
 Poisson's Ratio, ν_{xy} : 0.2200

Measured/Nominal Specimen Dimensions:

Width, W: 1.380(1.50) in
 Thickness, H: 0.461(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 6,476 lbs
 50% Max Load: 16,191 lbs

PICTURE OF SPECIMEN PRE-TEST



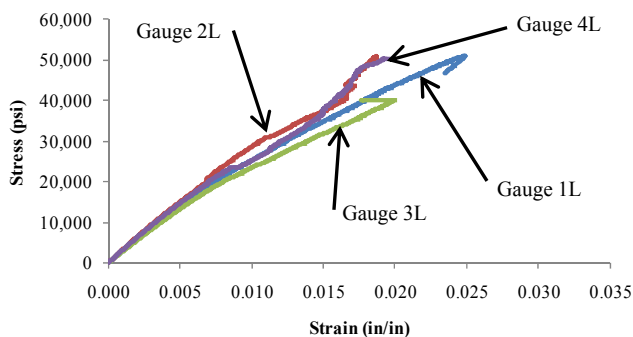
PICTURE OF SPECIMEN POST-TEST



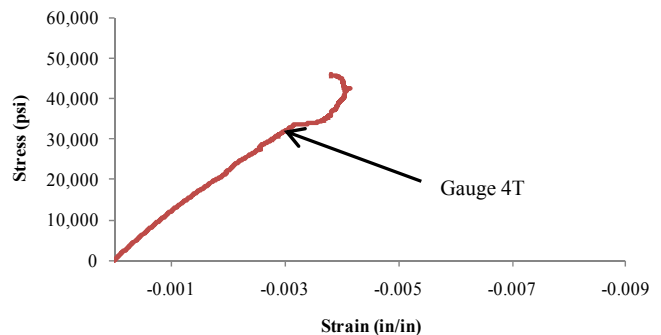
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L (CBW) | 0.0102 | 0.0035 | 2,214,300 | | | | |
| 2L (CBW) | 0.0101 | 0.0035 | 2,218,248 | | | | |
| 3L | 0.0111 | 0.0038 | 2,005,886 | 2T | -0.0038 | -0.0013 | 0.339958 |
| 4L | 0.0113 | 0.0036 | 1,914,709 | 4T | -0.0024 | -0.0009 | 0.19428 |
| Average | | | 2,088,286 | | | | |

Stress-Strain Curve N40_3, Long.



Stress-Strain Curve N40_3, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-4-N40-FY08**
 Test Date: 2/23/2010
 Specimen Received: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 37,447 lbs
 Tension Stress, ST_x : 52,520 psi
 Tensile Modulus, E_x : 2,139,112 psi
 Ultimate Strain, ϵ_x : 0.0246 in/in
 Poisson's Ratio, v_{xy} : 0.2712

Measured/Nominal Specimen Dimensions:

Width, W: 1.340(1.50) in
 Thickness, H: 0.532(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 7,489 lbs
 50% Max Load: 18,723 lbs

PICTURE OF SPECIMEN PRE-TEST



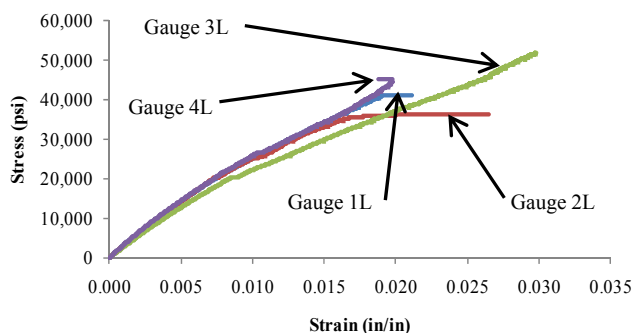
PICTURE OF SPECIMEN POST-TEST



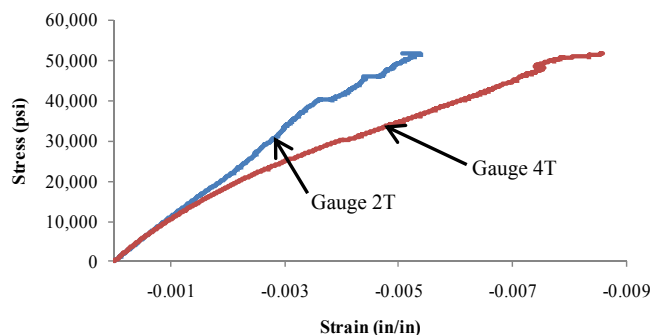
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0106 | 0.0036 | 2,259,969 | | | | |
| 2L | 0.0110 | 0.0037 | 2,138,501 | 2T | -0.0025 | -0.0009 | 0.20502 |
| 3L | 0.0127 | 0.0041 | 1,817,827 | | | | |
| 4L | 0.0102 | 0.0035 | 2,340,149 | 4T | -0.0033 | -0.0010 | 0.337398 |
| Average | | | 2,139,112 | Average | | | 0.27121 |

Stress-Strain Curve N40_4, Long.



Stress-Strain Curve N40_4, Lat.



Engineering Test notes:

- *Specimen 4 was fitted with one Vishay 20CBW strain gauges and three 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-N40-FY08**
 Test Date: 2/17/2010
 Specimen Received: 2/10/2010
 Properties Measured: ST_x , E_x , ν_{xy}

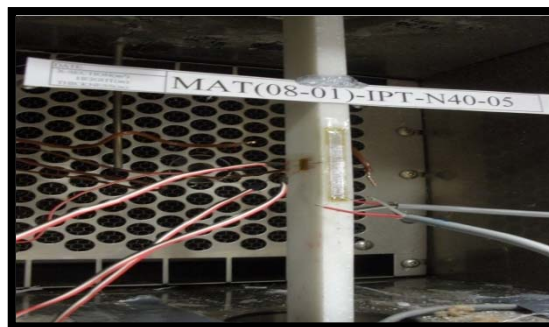
Average Material Properties:

Ultimate Load, P_x : 32,962 lbs
 Tension Stress, ST_x : 52,287 psi
 Tensile Modulus, E_x : 2,624,229 psi
 Ultimate Strain, ϵ_x : 0.0199 in/in
 Poisson's Ratio, ν_{xy} : 0.2786

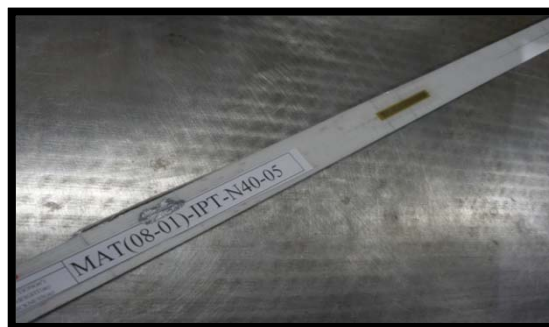
Measured/Nominal Specimen Dimensions:

Width, W: 1.347(1.50) in
 Thickness, H: 0.468(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 6,592 lbs
 50% Max Load: 16,481 lbs

PICTURE OF SPECIMEN PRE-TEST



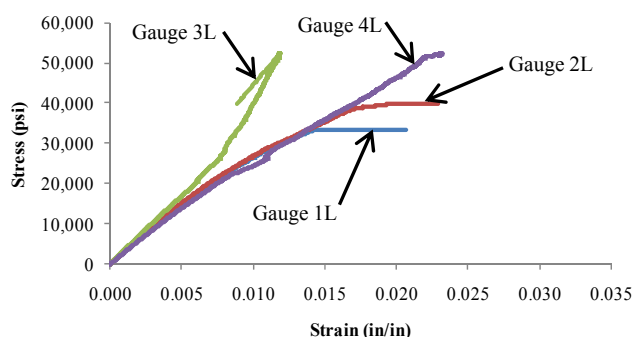
PICTURE OF SPECIMEN POST-TEST



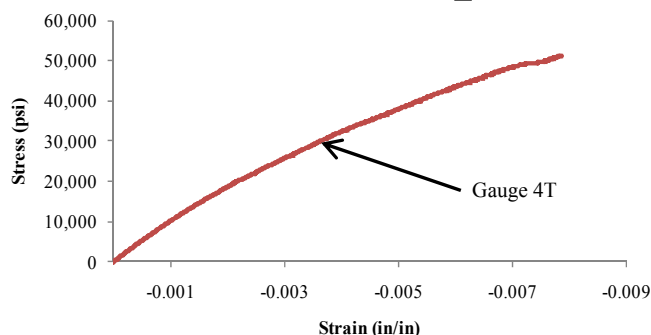
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L (CBW) | 0.0098 | 0.0034 | 2,443,842 | | | | |
| 2L (CBW) | 0.0096 | 0.0033 | 2,485,341 | | | | |
| 3L | 0.0076 | 0.0030 | 3,418,573 | | | | |
| 4L | 0.0110 | 0.0037 | 2,149,158 | 4T | -0.0031 | -0.0010 | 0.27856 |
| Average | | | 2,624,229 | | | | |

Stress-Strain Curve N40_5, Long.



Stress-Strain Curve N40_5, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TX-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: ST_x , E_x , ν_{xy}

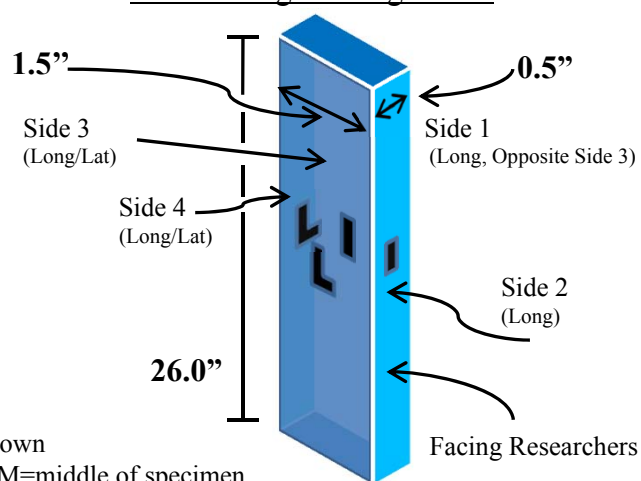
Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 30,618 | lbs |
| Tensile Strength, ST_x : | 48,035 | psi |
| Tensile Modulus, E_x : | 2,168,333 | psi |
| Ultimate Strain, ϵ_x : | 0.0222 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2128 | |

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson Ratio (ν_{xy}) | Failure Mode |
|----------------|-------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|------------------------------|--------------|
| 1 | MAT1-TX-1-70-FY08 | 31,002 | 49,265 | 2,161,088 | 0.0228 | 0.2040 | DGM |
| 2 | MAT1-TX-2-70-FY08 | 29,838 | 48,891 | 2,284,255 | 0.0214 | 0.2335 | DGM |
| 3 | MAT1-TX-3-70-FY08 | 29,941 | 48,972 | 2,088,286 | 0.0235 | 0.1943 | DGM |
| 4 | MAT1-TX-4-70-FY08 | 30,064 | 48,095 | 2,058,442 | 0.0234 | 0.2166 | DGM |
| 5 | MAT1-TX-5-70-FY08 | 32,242 | 44,951 | 2,249,593 | 0.0200 | 0.2155 | DGM |
| Average | | 30,618 | 48,035 | 2,168,333 | 0.0222 | 0.2128 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See B-8 to B-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-70-FY08**
 Test Date: 2/11/2010
 Specimen Rcvd.: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

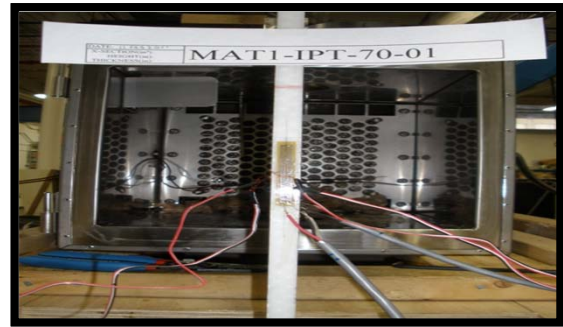
Average Material Properties:

Ultimate Load, P_x : 31,002 lbs
 Tension Stress, ST_x : 49,265 psi
 Tensile Modulus, E_x : 2,161,088 psi
 Ultimate Strain, ϵ_x : 0.0228 in/in
 Poisson Ratio, v_{xy} : 0.2040

Measured/Nominal Specimen Dimensions:

Width, W: 1.344(1.50) in
 Thickness, H: 0.468(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load 6,200 lbs
 50% Max Load: 15,501 lbs

PICTURE OF SPECIMEN PRE-TEST



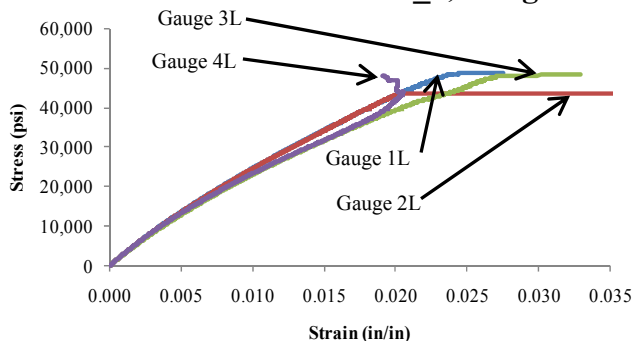
PICTURE OF SPECIMEN POST-TEST



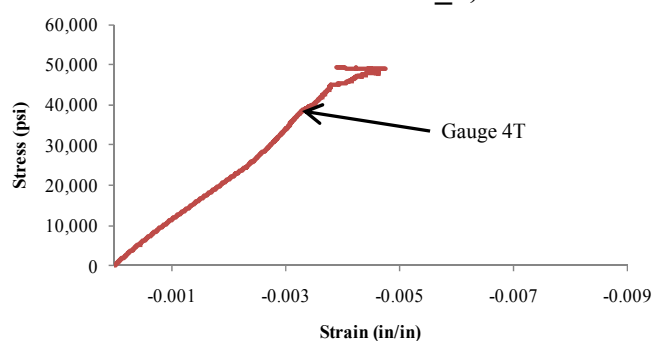
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0100 | 0.0035 | 2,266,952 | | | | |
| 2L (CBW) | 0.0100 | 0.0035 | 2,262,539 | | | | |
| 3L | 0.0109 | 0.0037 | 2,060,813 | | | | |
| 4L | 0.0107 | 0.0035 | 2,054,049 | 4T | -0.0023 | -0.0008 | 0.204046 |
| Average | | | 2,161,088 | | | | |

Stress-Strain Curve 70_1, Long.



Stress-Strain Curve 70_1, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MAT1-TX-2-70-FY08

Test Date: 2/22/2010

Specimen Rcvd.: 2/10/2010

Properties Measured: ST_x , E_x , v_{xy}

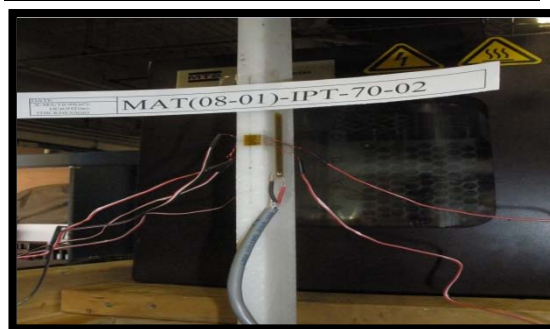
Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 29,838 | lbs |
| Tension Stress, ST_x : | 48,891 | psi |
| Tensile Modulus, E_x : | 2,284,255 | psi |
| Ultimate Strain, ϵ_x : | 0.0214 | in/in |
| Poisson Ratio, v_{xy} : | 0.2335 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|----------------------|-----|
| Width, W: | 1.334(1.50) | in |
| Thickness, H: | 0.458(0.50) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Tensile Delamination | |
| 20% Max Load | 5,968 | lbs |
| 50% Max Load: | 14,919 | lbs |

PICTURE OF SPECIMEN PRE-TEST



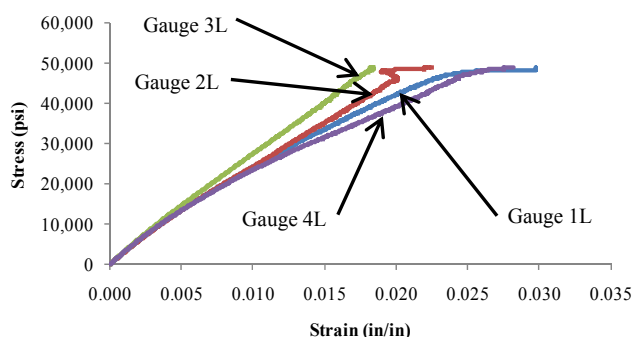
PICTURE OF SPECIMEN POST-TEST



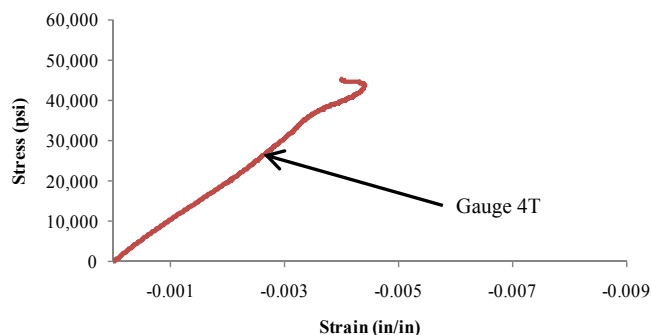
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0101 | 0.0035 | 2,210,033 | | | | |
| 2L | 0.0101 | 0.0035 | 2,234,807 | 2T | -0.0025 | -0.0009 | 0.233456 |
| 3L | 0.0088 | 0.0032 | 2,625,807 | | | | |
| 4L | 0.0106 | 0.0035 | 2,066,374 | | | | |
| Average | | | 2,284,255 | | | | |

Stress-Strain Curve 70_2, Long.



Stress-Strain Curve 70_2, Lat.



Engineering Test notes:

- *Specimen 2 was fitted with one Vishay 20CBW strain gauges and three 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-3-70-FY08**

Test Date: 2/14/2010

Specimen Rcvd.: 2/10/2010

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 29,941 | lbs |
| Tension Stress, ST_x : | 48,972 | psi |
| Tensile Modulus, E_x : | 2,088,286 | psi |
| Ultimate Strain, ϵ_x : | 0.0235 | in/in |
| Poisson Ratio, ν_{xy} : | 0.1943 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|----------------------|-----|
| Width, W: | 1.340(1.50) | in |
| Thickness, H: | 0.456(0.50) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Tensile Delamination | |
| 20% Max Load | 5,988 | lbs |
| 50% Max Load: | 14,971 | lbs |

PICTURE OF SPECIMEN PRE-TEST



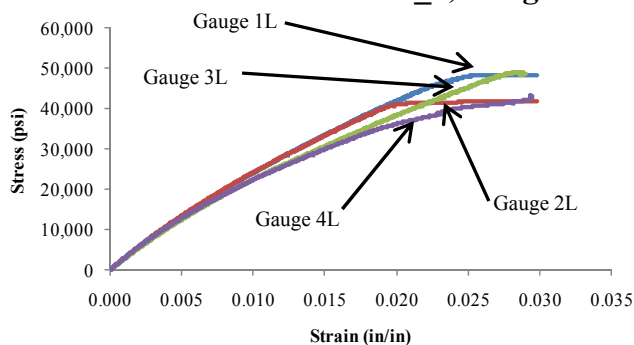
PICTURE OF SPECIMEN POST-TEST



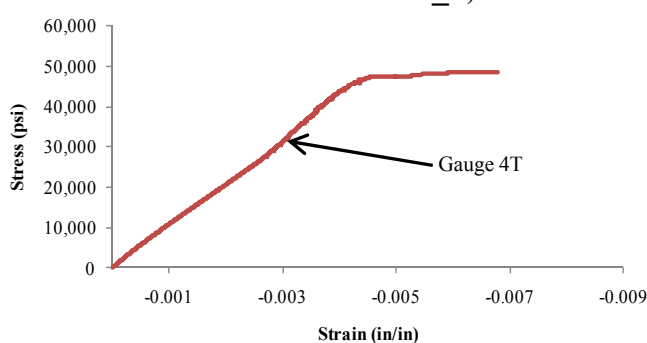
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L (CBW) | 0.0102 | 0.0035 | 2,214,300 | | | | |
| 2L (CBW) | 0.0101 | 0.0035 | 2,218,248 | | | | |
| 3L | 0.0111 | 0.0038 | 2,005,886 | | | | |
| 4L | 0.0113 | 0.0036 | 1,914,709 | 4T | -0.0024 | -0.0009 | 0.19428 |
| Average | | | 2,088,286 | | | | |

Stress-Strain Curve 70_3, Long.



Stress-Strain Curve 70_3, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-4-70-FY08**
 Test Date: 2/14/2010
 Specimen Rcvd.: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,064 lbs
 Tension Stress, ST_x : 48,095 psi
 Tensile Modulus, E_x : 2,058,442 psi
 Ultimate Strain, ϵ_x : 0.0234 in/in
 Poisson Ratio, v_{xy} : 0.2166

Measured/Nominal Specimen Dimensions:

Width, W: 1.351(1.50) in
 Thickness, H: 0.463(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 6,013 lbs
 50% Max Load: 15,032 lbs

PICTURE OF SPECIMEN PRE-TEST



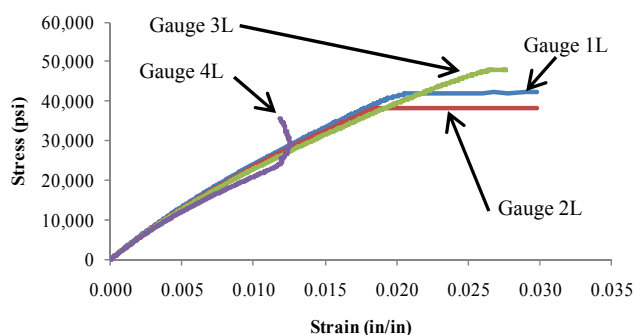
PICTURE OF SPECIMEN POST-TEST



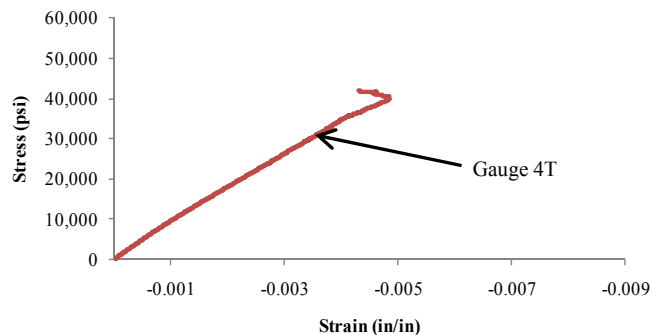
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L (CBW) | 0.0100 | 0.0035 | 2,213,749 | | | | |
| 2L (CBW) | 0.0103 | 0.0036 | 2,150,225 | | | | |
| 3L | 0.0106 | 0.0036 | 2,064,171 | | | | |
| 4L | 0.0118 | 0.0038 | 1,805,622 | 4T | -0.0027 | -0.0010 | 0.216571 |
| Average | | | 2,058,442 | | | | |

Stress-Strain Curve 70_4, Long.



Stress-Strain Curve 70_4, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-70-FY08**

Test Date: 2/14/2010

Specimen Rcvd.: 2/10/2010

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 32,242 | lbs |
| Tension Stress, ST_x : | 44,951 | psi |
| Tensile Modulus, E_x : | 2,249,593 | psi |
| Ultimate Strain, ϵ_x : | 0.0200 | in/in |
| Poisson Ratio, ν_{xy} : | 0.2155 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|----------------------|-----|
| Width, W: | 1.339(1.50) | in |
| Thickness, H: | 0.485(0.50) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Tensile Delamination | |
| 20% Max Load | 6,448 | lbs |
| 50% Max Load: | 16,121 | lbs |

PICTURE OF SPECIMEN PRE-TEST



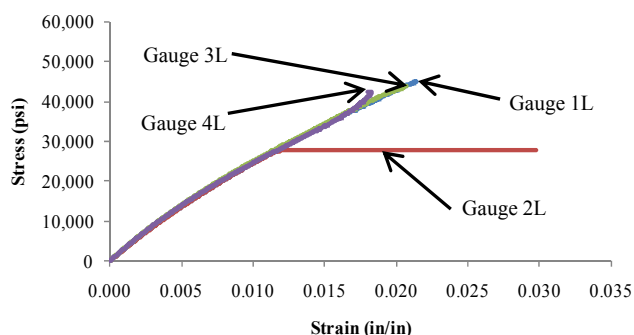
PICTURE OF SPECIMEN POST-TEST



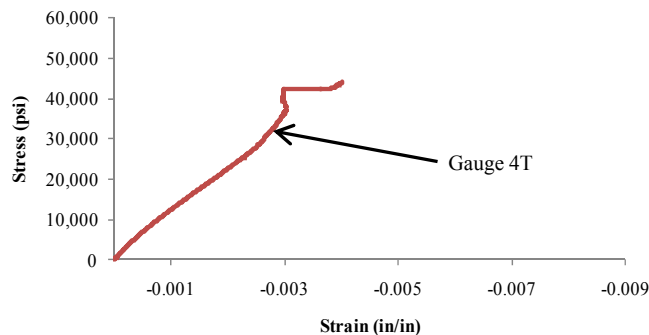
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L (CBW) | 0.0101 | 0.0035 | 2,246,014 | | | | |
| 2L (CBW) | 0.0102 | 0.0035 | 2,249,714 | | | | |
| 3L | 0.0099 | 0.0034 | 2,285,792 | | | | |
| 4L | 0.0101 | 0.0034 | 2,216,853 | 4T | -0.0022 | -0.0008 | 0.215528 |
| Average | | | 2,249,593 | | | | |

Stress-Strain Curve 70_5, Long.



Stress-Strain Curve 70_5, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125-LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

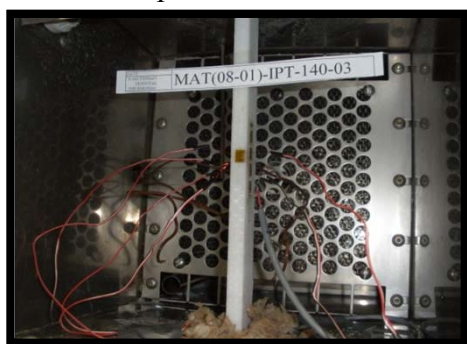
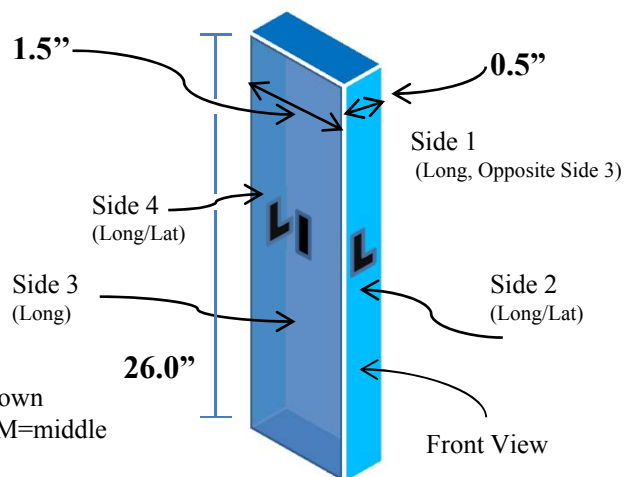
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TX-140-FY08
Material: Huntsman Epoxy SC-15, S2 Glass
Nominal Temperature: 140°F
Properties Measured: ST_x , E_x , ν_{xy}
Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 27,596 lbs
 Tensile Strength, ST_x : 42,203 psi
 Tensile Modulus, E_x : 2,180,534 psi
 Ultimate Strain, ϵ_x : 0.0194 in/in
 Poisson's Ratio, ν_{xy} : 0.2666

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|-----------------------------|--------------------------------------|------------------------------------|---|-----------------------------------|-----------------|
| 1 | MAT1-TX-1-140-FY08 | 26,097 | 42,258 | 2,082,470 | 0.0203 | 0.2951 | DGM |
| 2 | MAT1-TX-2-140-FY08 | 26,960 | 42,377 | 2,127,285 | 0.0199 | 0.2464 | DGM |
| 3 | MAT1-TX-3-140-FY08 | 26,803 | 41,980 | 2,258,384 | 0.0186 | 0.2601 | DGM |
| 4 | MAT1-TX-5-140-FY08 | 29,336 | 43,024 | 2,334,089 | 0.0184 | 0.2614 | DGM |
| 5 | MAT1-TX-6-140-FY08 | 28,786 | 41,378 | 2,100,441 | 0.0197 | 0.2699 | DGM |
| Average | | 27,596 | 42,203 | 2,180,534 | 0.0194 | 0.2666 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See B-14 to B-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-140-FY08**
 Test Date: 2/17/2010
 Specimen Received.: 2/10/2010
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 26,097 lbs
 Tensile Strength, ST_x : 42,258 psi
 Tensile Modulus, E_x : 2,082,470 psi
 Ultimate Strain, ϵ_x : 0.0203 in/in
 Poisson's Ratio, ν_{xy} : 0.2951

Measured/Nominal Specimen Dimensions:

Width, W: 1.344 (1.50) in
 Thickness, H: 0.4595 (0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 5,219 lbs
 50% Max Load: 13,049 lbs

PICTURE OF SPECIMEN PRE-TEST



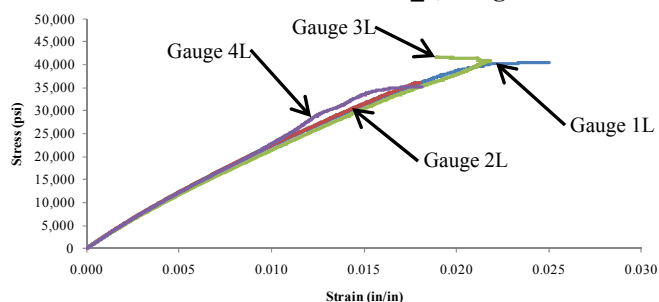
PICTURE OF SPECIMEN POST-TEST



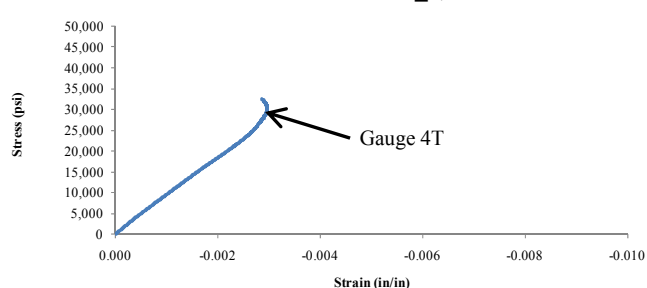
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0094 | 0.0033 | 2,092,319 | | | | |
| 2L | 0.0093 | 0.0033 | 2,109,713 | | | | |
| 3L | 0.0098 | 0.0035 | 1,991,988 | | | | |
| 4L | 0.0093 | 0.0033 | 2,135,862 | 4T | -0.0027 | -0.0009 | 0.2951 |
| Average | | | 2,082,470 | | | | 0.2951 |

Stress-Strain Curve 140_1, Long.



Stress-Strain Curve 140_1, Lat.



Engineering Test notes:

- *Specimen was fitted with two Vishay 20CBW strain gauges and two 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-2-140-FY08**

Test Date: 2/17/2010

Specimen Received.: 2/10/2010

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 26,960 | lbs |
| Tensile Strength, ST_x : | 42,377 | psi |
| Tensile Modulus, E_x : | 2,127,285 | psi |
| Ultimate Strain, ϵ_x : | 0.0199 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2464 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|----------------------|-----|
| Width, W: | 1.349 (1.50) | in |
| Thickness, H: | 0.4716 (0.50) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Tensile Delamination | |
| 20% Max Load: | 5,392 | lbs |
| 50% Max Load: | 13,480 | lbs |

PICTURE OF SPECIMEN PRE-TEST



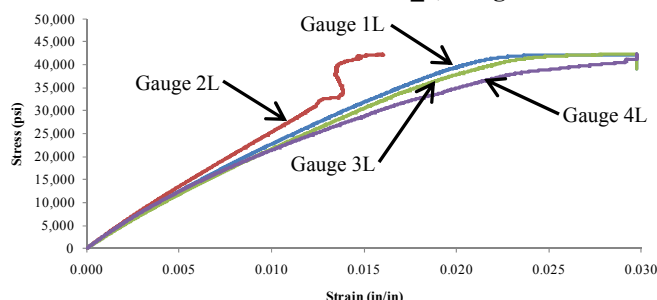
PICTURE OF SPECIMEN POST-TEST



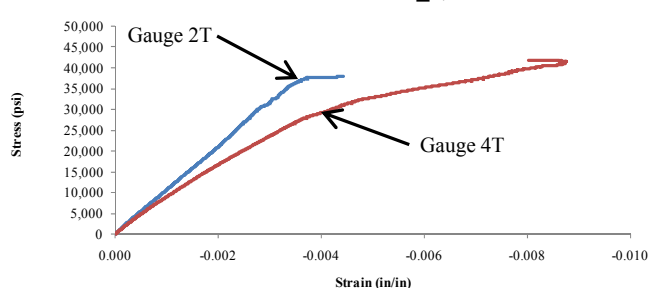
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0092 | 0.0032 | 2,135,674 | | | | |
| 2L | 0.0082 | 0.0030 | 2,438,538 | 2T | -0.0020 | -0.0008 | 0.2358 |
| 3L | 0.0097 | 0.0035 | 2,025,352 | | | | |
| 4L | 0.0099 | 0.0032 | 1,909,578 | 4T | -0.0026 | -0.0009 | 0.2570 |
| Average | | | 2,127,285 | | | | 0.2464 |

Stress-Strain Curve 140_2, Long.



Stress-Strain Curve 140_2, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-3-140-FY08**

Test Date: 2/18/2010

Specimen Received.: 2/10/2010

Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 26,803 | lbs |
| Tensile Strength, ST_x : | 41,980 | psi |
| Tensile Modulus, E_x : | 2,258,384 | psi |
| Ultimate Strain, ϵ_x : | 0.0186 | in/in |
| Poisson's Ratio, v_{xy} : | 0.2601 | |

Measured/Nominal Specimen Dimensions:

| | | |
|-------------------------|----------------------|-----|
| Width, W: | 1.351(1.50) | in |
| Thickness, H: | 0.4726(0.50) | in |
| Laboratory Temperature: | 68°F | |
| Failure Mode: | Tensile Delamination | |
| 20% Max Load: | 5,361 | lbs |
| 50% Max Load: | 13,402 | lbs |

PICTURE OF SPECIMEN PRE-TEST



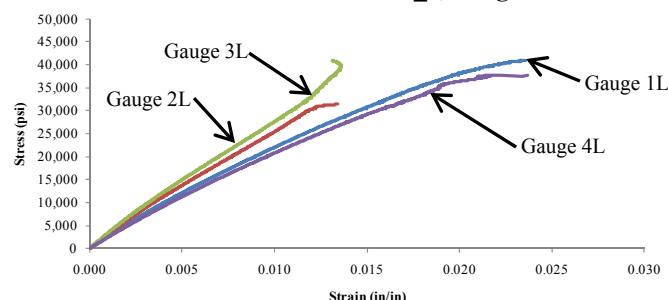
PICTURE OF SPECIMEN POST-TEST



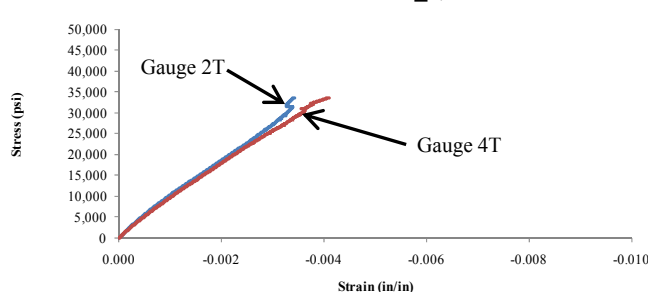
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0094 | 0.0033 | 2,049,984 | | | | |
| 2L | 0.0081 | 0.0028 | 2,403,969 | 2T | -0.0023 | -0.0008 | 0.285926 |
| 3L | 0.0074 | 0.0026 | 2,642,167 | | | | |
| 4L | 0.0101 | 0.0036 | 1,937,417 | 4T | -0.0024 | -0.0009 | 0.234319 |
| Average | | | 2,258,384 | | | | 0.26012 |

Stress-Strain Curve 140_3, Long.



Stress-Strain Curve 140_3, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-140-FY08**
 Test Date: 2/18/2010
 Specimen Received.: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

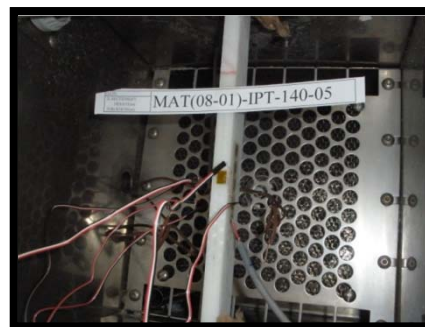
Average Material Properties:

Ultimate Load, P_x : 29,336 lbs
 Tensile Strength, ST_x : 43,024 psi
 Tensile Modulus, E_x : 2,334,089 psi
 Ultimate Strain, ϵ_x : 0.0184 in/in
 Poisson's Ratio, v_{xy} : 0.2614

Measured/Nominal Specimen Dimensions:

Width, W: 1.351(1.50) in
 Thickness, H: 0.5047(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 5,867 lbs
 50% Max Load: 14,668 lbs

PICTURE OF SPECIMEN PRE-TEST



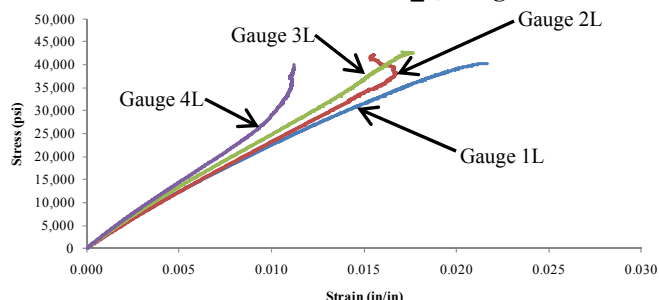
PICTURE OF SPECIMEN POST-TEST



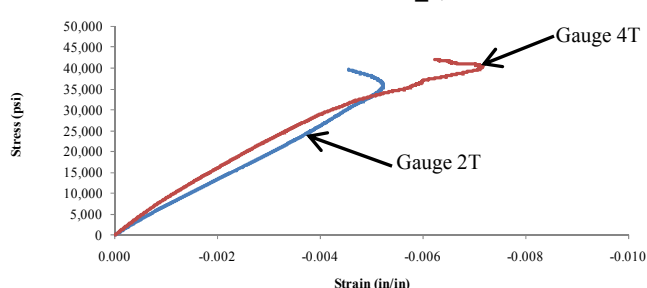
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0095 | 0.0033 | 2,105,917 | | | | |
| 2L | 0.0092 | 0.0034 | 2,225,991 | 2T | -0.0024 | -0.0009 | 0.2614 |
| 3L | 0.0085 | 0.0030 | 2,351,212 | | | | |
| 4L | 0.0077 | 0.0028 | 2,653,235 | | | | |
| Average | | | 2,334,089 | | | | 0.2614 |

Stress-Strain Curve 140_5, Long.



Stress-Strain Curve 140_5, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-6-140-FY08**
 Test Date: 2/25/2010
 Specimen Received.: 2/10/2010
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 28,786 lbs
 Tensile Strength, ST_x : 41,378 psi
 Tensile Modulus, E_x : 2,100,441 psi
 Ultimate Strain, ϵ_x : 0.0197 in/in
 Poisson's Ratio, v_{xy} : 0.2699

Measured/Nominal Specimen Dimensions:

Width, W: 1.343(1.50) in
 Thickness, H: 0.5067(0.50) in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 5,757 lbs
 50% Max Load: 14,393 lbs

PICTURE OF SPECIMEN PRE-TEST



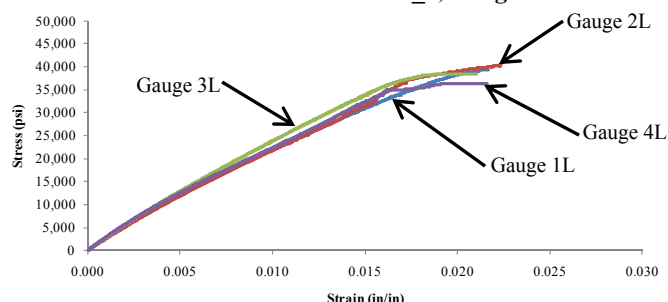
PICTURE OF SPECIMEN POST-TEST



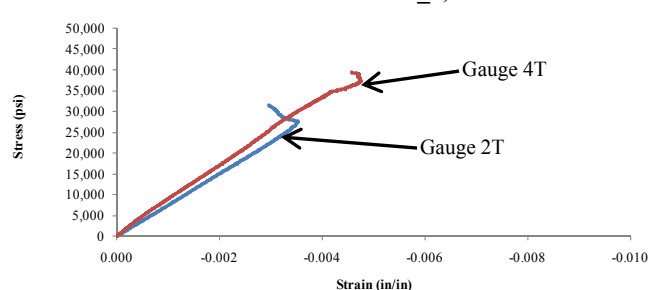
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0095 | 0.0033 | 2,039,709 | | | | |
| 2L | 0.0097 | 0.0034 | 2,040,901 | 2T | -0.0028 | -0.0010 | 0.2879 |
| 3L | 0.0087 | 0.0031 | 2,271,871 | | | | |
| 4L | 0.0093 | 0.0031 | 2,049,282 | 4T | -0.0025 | -0.0009 | 0.2519 |
| Average | | | 2,100,441 | | | | 0.2699 |

Stress-Strain Curve 140_6, Long.



Stress-Strain Curve 140_6, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_x, E_x, ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x: 63,506 lbs
 Compressive Strength, SC_x: 45,804 psi
 Compressive Modulus, E_x: 2,861,819 psi
 Ultimate Strain, ε_x: 0.016 in/in
 Poisson's Ratio, ν_{xy}: 0.312

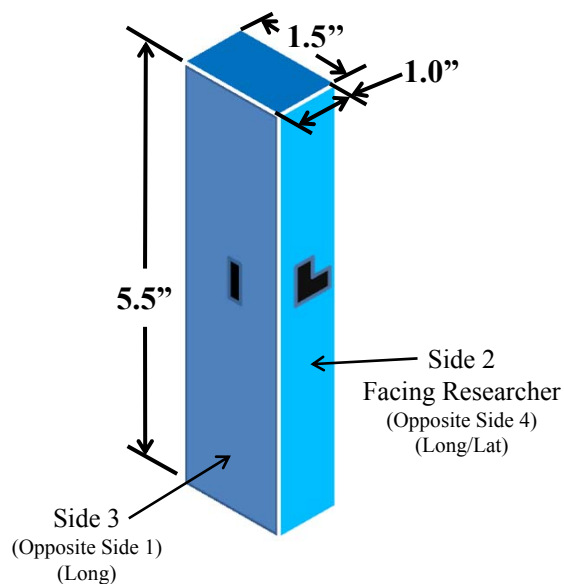
| Sample | Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|----------------|---------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| 1 | MAT1-CX-01-N40-FY08 | 63,793 | 46,405 | 2,883,238 | 0.015 | 0.371 | Delam |
| 2 | MAT1-CX-02-N40-FY08 | 61,650 | 44,526 | 3,094,891 | 0.015 | 0.313 | Delam |
| 3 | MAT1-CX-03-N40-FY08 | 64,816 | 47,022 | 2,728,781 | 0.017 | 0.293 | Delam |
| 4 | MAT1-CX-04-N40-FY08 | 65,360 | 46,719 | 2,673,497 | 0.017 | 0.278 | Delam |
| 5 | MAT1-CX-05-N40-FY08 | 61,911 | 44,349 | 2,928,688 | 0.015 | 0.303 | Delam |
| Average | | 63,506 | 45,804 | 2,861,819 | 0.016 | 0.312 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees, the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See B-20 to B-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-01-N40-FY08
 Test Date: 3/24/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 63,793 lbs
 Compressive Strength, SC_x : 46,405 psi
 Compressive Modulus, E_x : 2,883,238 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.371

Measured Specimen Dimensions:

Width, W: 0.99 in
 Thickness, H: 1.39 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 12,759 lbs
 50% Max Load: 31,896 lbs

PICTURE OF SPECIMEN PRE-TEST



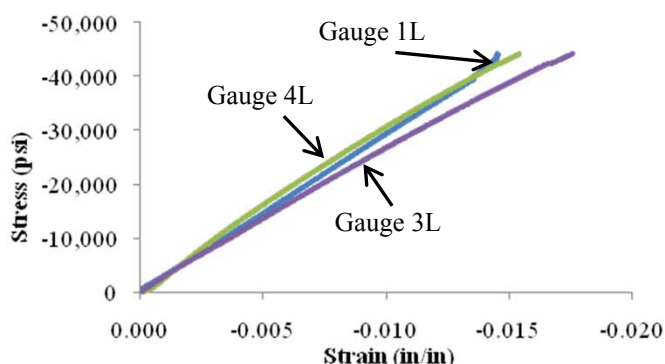
PICTURE OF SPECIMEN POST-TEST



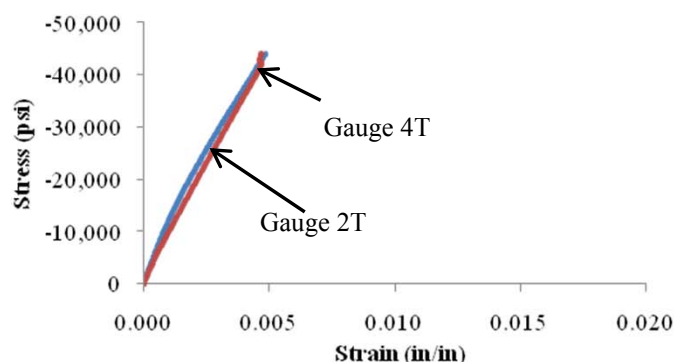
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0079 | -0.0032 | 2,929,580 | | | | |
| 2L | Lost Gauge | Lost Gauge | - | 2T | 0.0022 | 0.0007 | 0.0442 |
| 3L | -0.0074 | -0.0029 | 3,072,887 | | | | |
| 4L | -0.0086 | -0.0034 | 2,647,247 | 4T | 0.0025 | 0.0009 | 0.301 |
| Average | | | 2,883,238 | | | | 0.371 |

Stress-Strain Curve N40_01_(08-01), Long



Stress-Strain Curve N40_01_(08-01), Lat



Engineering Test Notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-02-N40-FY08**
 Test Date: 3/28/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 61,650 lbs
 Compressive Strength, SC_x : 44,526 psi
 Compressive Modulus, E_x : 3,094,891 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.313

Measured Specimen Dimensions:

Width, W: 0.99 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 12,330 lbs
 50% Max Load: 30,825 lbs

PICTURE OF SPECIMEN PRE-TEST



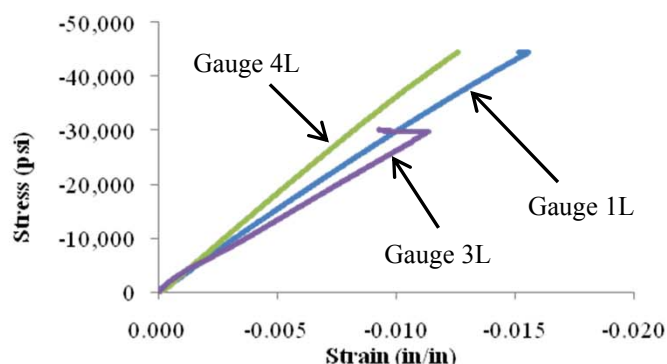
PICTURE OF SPECIMEN POST-TEST



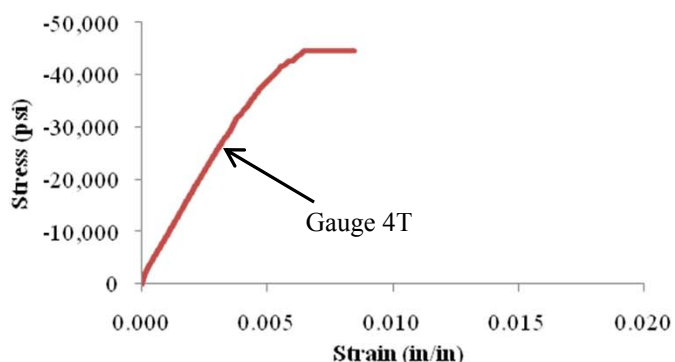
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0074 | -0.0029 | 2,974,691 | | | | |
| 2L | Lost Gauge | Lost Gauge | - | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.0061 | -0.0025 | 3,728,924 | | | | |
| 4L | -0.0084 | -0.0033 | 2,581,059 | 4T | 0.0026 | 0.0010 | 0.313 |
| Average | | | 3,094,891 | | | | 0.313 |

Stress-Strain Curve N40_02_(08-01), Long



Stress-Strain Curve N40_02_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-03-N40-FY08
 Test Date: 4/1/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 64,816 lbs
 Compressive Strength, SC_x : 47,022 psi
 Compressive Modulus, E_x : 2,728,781 psi
 Ultimate Strain, ϵ_x : 0.017 in/in
 Poisson's Ratio, v_{xy} : 0.293

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 12,963 lbs
 50% Max Load: 32,408 lbs

PICTURE OF SPECIMEN PRE-TEST



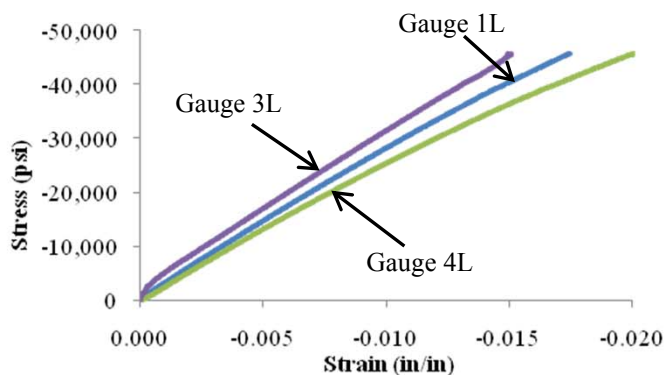
PICTURE OF SPECIMEN POST-TEST



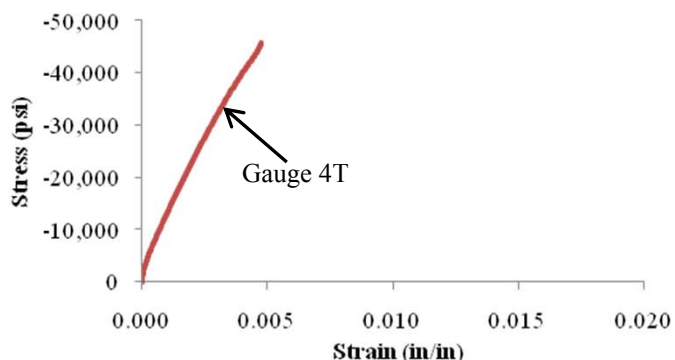
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.0082 | -0.0031 | 2,763,626 | | | | |
| 2L | Lost Gauge | Lost Gauge | - | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.0092 | -0.0036 | 2,492,230 | | | | |
| 4L | -0.0072 | -0.0024 | 2,930,487 | 4T | 0.0021 | 0.0006 | 0.293 |
| Average | | | 2,728,781 | | | | 0.293 |

Stress-Strain Curve N40_03_(08-01), Long



Stress-Strain Curve N40_03_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-04-N40-FY08
 Test Date: 4/1/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 65,360 lbs
 Compressive Strength, SC_x : 46,719 psi
 Compressive Modulus, E_x : 2,673,497 psi
 Ultimate Strain, ϵ_x : 0.017 in/in
 Poisson's Ratio, ν_{xy} : 0.278

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 13,072 lbs
 50% Max Load: 32,680 lbs

PICTURE OF SPECIMEN PRE-TEST



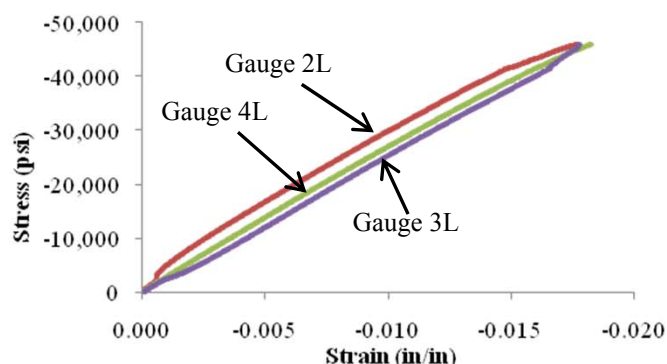
PICTURE OF SPECIMEN POST-TEST



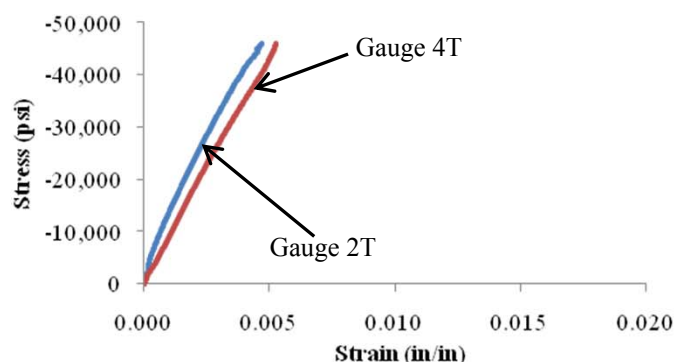
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.0075 | -0.0023 | 2,713,937 | 2T | 0.0020 | 0.0006 | 0.265 |
| 3L | -0.0086 | -0.0033 | 2,651,452 | | | | |
| 4L | -0.0093 | -0.0040 | 2,655,101 | 4T | 0.0026 | 0.0010 | 0.290 |
| Average | | | 2,673,497 | | | | 0.278 |

Stress-Strain Curve N40_04_(08-01), Long



Stress-Strain Curve N40_04_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-05-N40-FY08
 Test Date: 4/1/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 61,911 lbs
 Compressive Strength, SC_x : 44,349 psi
 Compressive Modulus, E_x : 2,928,688 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.303

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.39 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 12,382 lbs
 50% Max Load: 30,956 lbs

PICTURE OF SPECIMEN PRE-TEST



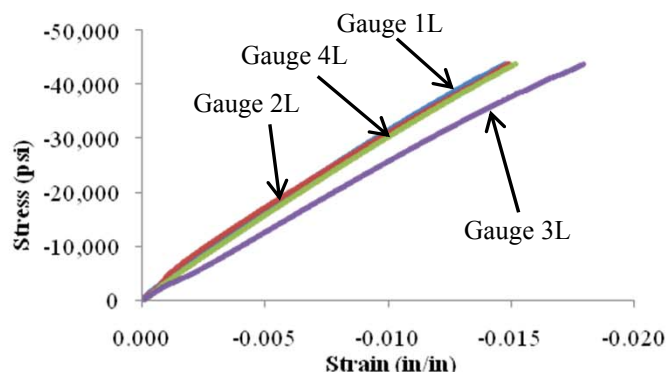
PICTURE OF SPECIMEN POST-TEST



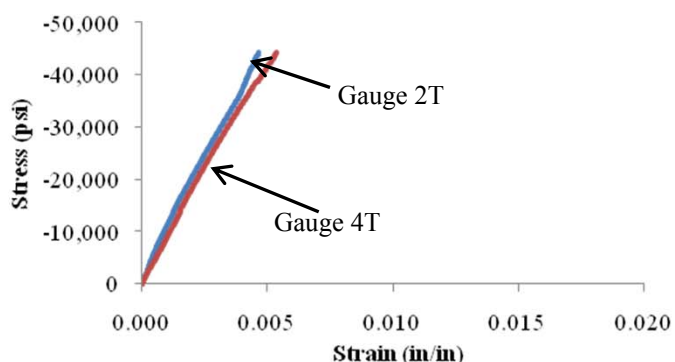
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0068 | -0.0025 | 3,120,706 | | | | |
| 2L | -0.0068 | -0.0023 | 2,942,667 | 2T | 0.0022 | 0.0008 | 0.317 |
| 3L | -0.0072 | -0.0027 | 3,000,531 | | | | |
| 4L | -0.0086 | -0.0036 | 2,650,850 | 4T | 0.0025 | 0.0010 | 0.290 |
| Average | | | 2,928,688 | | | | 0.303 |

Stress-Strain Curve N40_05_(08-01), Long



Stress-Strain Curve N40_05_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: SC_x , E_x , ν_{xy}

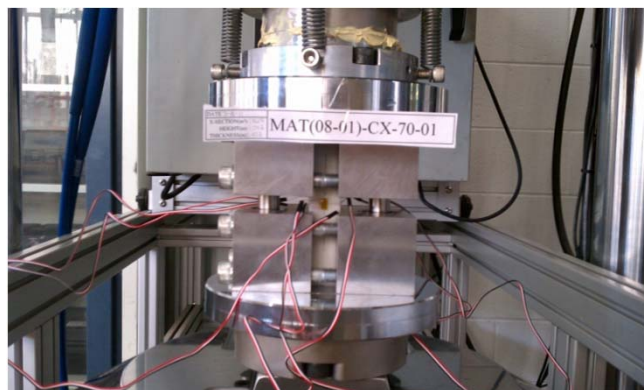
Average Material Properties (5 Specimens):

Ultimate Load, P_x : 56,634 lbs
 Compressive Strength, SC_x : 40,268 psi
 Compressive Modulus, E_x : 2,870,964 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.325

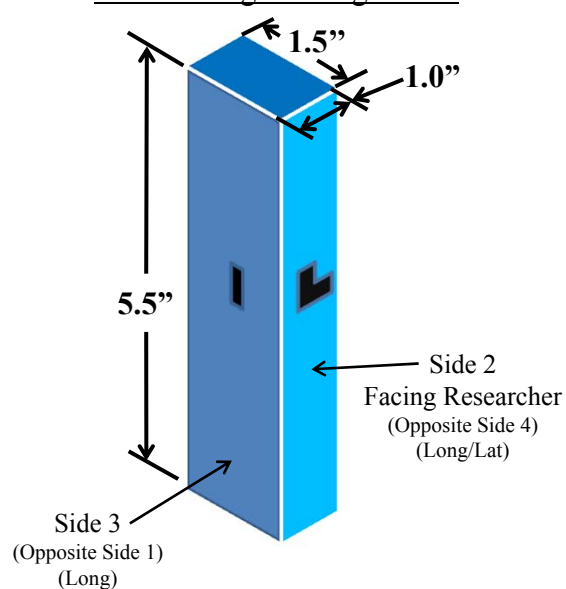
| Sample | Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT1- CX-01-70-FY08 | 60,817 | 41,630 | 2,724,311 | 0.015 | 0.294 | Delam |
| 2 | MAT1- CX-02-70-FY08 | 54,774 | 39,237 | 2,767,682 | 0.014 | 0.279 | Delam |
| 3 | MAT1- CX-03-70-FY08 | 54,851 | 40,164 | 3,007,855 | 0.013 | 0.383 | Delam |
| 4 | MAT1- CX-04-70-FY08 | 58,441 | 41,293 | 2,977,316 | 0.014 | 0.351 | Delam |
| 5 | MAT1- CX-05-70-FY08 | 54,288 | 39,017 | 2,877,657 | 0.014 | 0.317 | Delam |
| Average | | 56,634 | 40,268 | 2,870,964 | 0.014 | 0.325 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the thickness.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See B-26 to B-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-01-70-FY08
 Test Date: 3/18/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 60,817 lbs
 Compressive Strength, SC_x : 41,630 psi
 Compressive Modulus, E_x : 2,724,311 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.294

Measured Specimen Dimensions:

Width, W: 1.04 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 12,163 lbs
 50% Max Load: 30,408 lbs

PICTURE OF SPECIMEN PRE-TEST



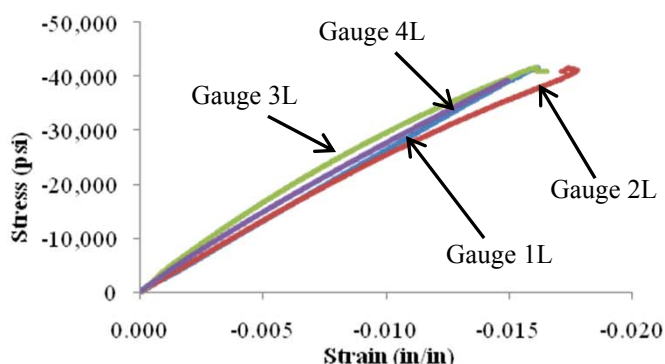
PICTURE OF SPECIMEN POST-TEST



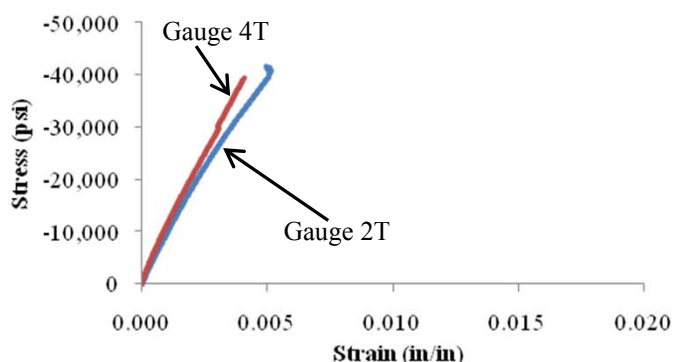
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0079 | -0.0032 | 2,662,732 | | | | |
| 2L | -0.0080 | -0.0031 | 2,563,451 | 2T | 0.0023 | 0.0009 | 0.298 |
| 3L | -0.0065 | -0.0023 | 2,968,556 | | | | |
| 4L | -0.0073 | -0.0026 | 2,702,506 | 4T | 0.0020 | 0.0007 | 0.289 |
| Average | | | 2,724,311 | | | | 0.294 |

Stress-Strain Curve 70_01_(08-01), Long



Stress-Strain Curve 70_01_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-02-70-FY08**
 Test Date: 3/18/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 54,774 lbs
 Compressive Strength, SC_x : 39,237 psi
 Compressive Modulus, E_x : 2,767,682 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, v_{xy} : 0.279

Measured Specimen Dimensions:

Width, W: 0.99 in
 Thickness, H: 1.39 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 10,955 lbs
 50% Max Load: 27,387 lbs

PICTURE OF SPECIMEN PRE-TEST



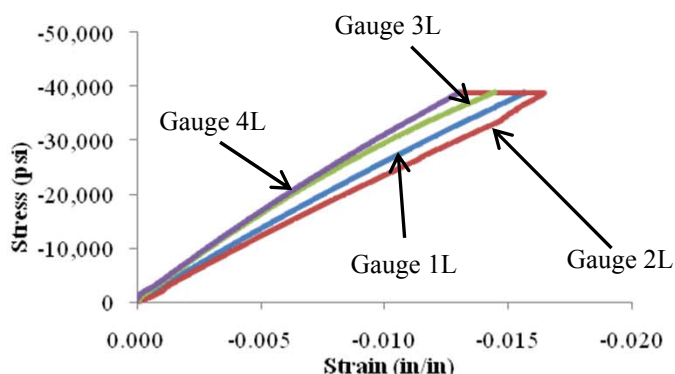
PICTURE OF SPECIMEN POST-TEST



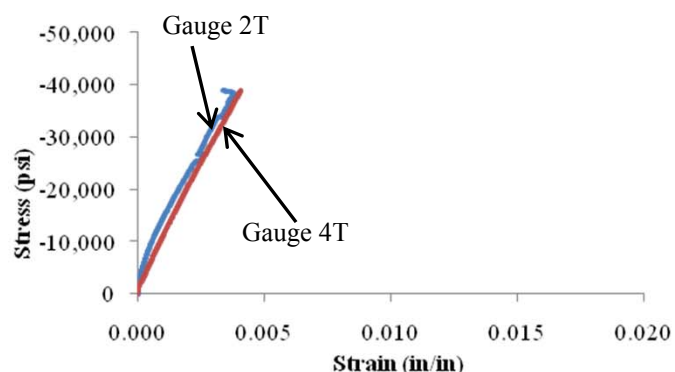
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | -0.0074 | -0.0028 | 2,579,608 | | | | |
| 2L | -0.0082 | -0.0032 | 2,341,031 | 2T | 0.0016 | 0.0004 | 0.236 |
| 3L | -0.0061 | -0.0022 | 3,018,153 | | | | |
| 4L | -0.0059 | -0.0022 | 3,131,935 | 4T | 0.0019 | 0.0007 | 0.322 |
| Average | | | 2,767,682 | | | | 0.279 |

Stress-Strain Curve 70_02_(08-01), Long



Stress-Strain Curve 70_02_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-03-70-FY08**
 Test Date: 3/18/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 54,851 lbs
 Compressive Strength, SC_x : 40,164 psi
 Compressive Modulus, E_x : 3,007,855 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.383

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 10,970 lbs
 50% Max Load: 27,426 lbs

PICTURE OF SPECIMEN PRE-TEST



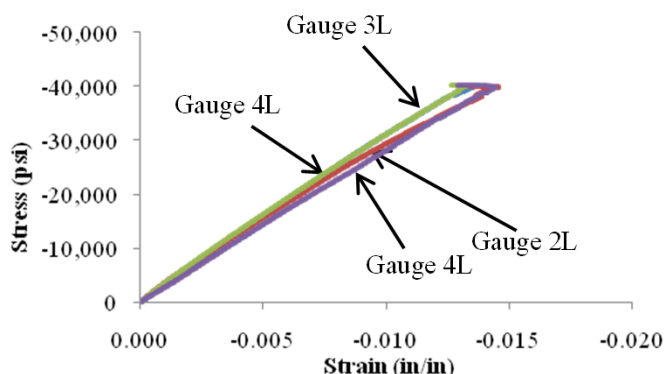
PICTURE OF SPECIMEN POST-TEST



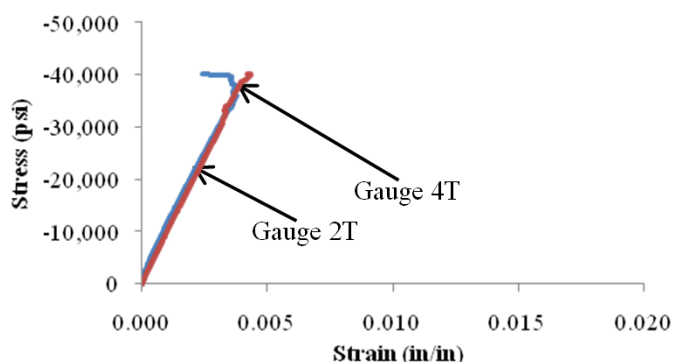
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0063 | -0.0025 | 3,161,608 | | | | |
| 2L | -0.0066 | -0.0024 | 2,904,139 | 2T | 0.0019 | 0.0007 | 0.463 |
| 3L | -0.0062 | -0.00224 | 3,105,363 | | | | |
| 4L | -0.0070 | -0.0028 | 2,860,308 | 4T | 0.0021 | 0.0008 | 0.302 |
| Average | | | 3,007,855 | | | | 0.383 |

Stress-Strain Curve 70_03_(08-01), Long



Stress-Strain Curve 70_03_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-04-70-FY08**
 Test Date: 3/18/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 58,441 lbs
 Compressive Strength, SC_x : 41,923 psi
 Compressive Modulus, E_x : 2,977,316 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.351

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 11,688 lbs
 50% Max Load: 29,220 lbs

PICTURE OF SPECIMEN PRE-TEST



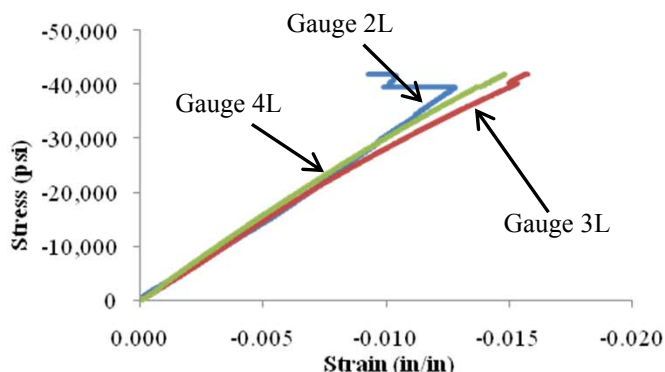
PICTURE OF SPECIMEN POST-TEST



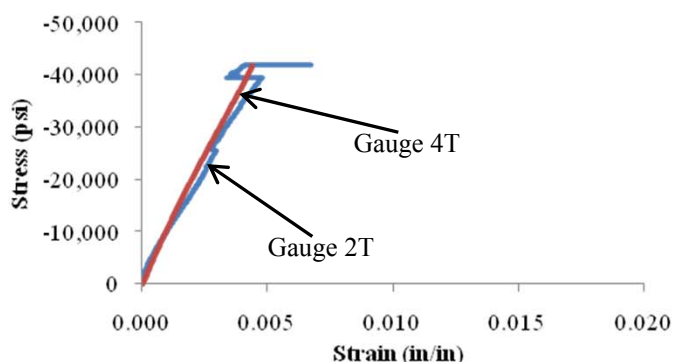
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.0072 | -0.0029 | 2,918,889 | 2T | 0.0025 | 0.0008 | 0.390 |
| 3L | -0.0072 | -0.0030 | 2,956,279 | | | | |
| 4L | -0.0067 | -0.0026 | 3,056,780 | 4T | 0.0021 | 0.0008 | 0.313 |
| Average | | | 2,977,316 | | | | 0.351 |

Stress-Strain Curve 70_04_(08-01), Long



Stress-Strain Curve 70_04_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-05-70-FY08**
 Test Date: 3/18/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 54,288 lbs
 Compressive Strength, SC_x : 39,017 psi
 Compressive Modulus, E_x : 2,877,657 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, v_{xy} : 0.317

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.40 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 10,858 lbs
 50% Max Load: 27,144 lbs

PICTURE OF SPECIMEN PRE-TEST



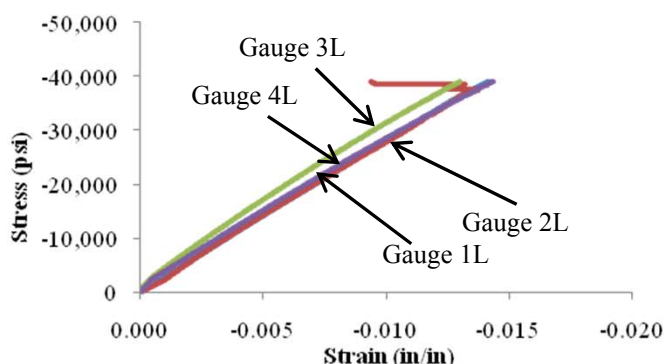
PICTURE OF SPECIMEN POST-TEST



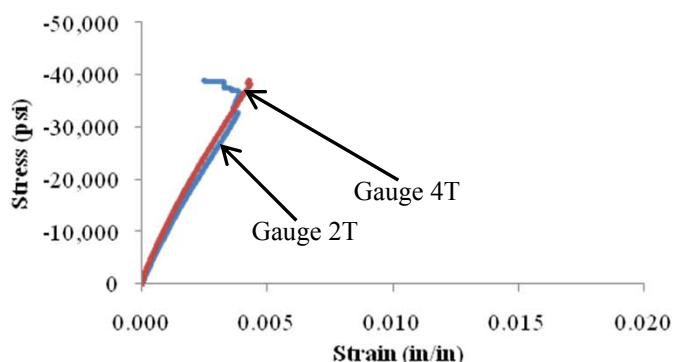
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | -0.0069 | -0.0028 | 2,808,900 | | | | |
| 2L | -0.0069 | -0.0027 | 2,818,730 | 2T | 0.0022 | 0.0007 | 0.332 |
| 3L | -0.0058 | -0.0020 | 3,087,502 | | | | |
| 4L | -0.0066 | -0.0024 | 2,795,496 | 4T | 0.0019 | 0.0006 | 0.302 |
| Average | | | 2,877,657 | | | | 0.317 |

Stress-Strain Curve 70_05_(08-01), Long



Stress-Strain Curve 70_05_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-140-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: SC_x, E_x, ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x: 46,496 lbs

Compressive Strength, SC_x: 33,235 psi

Compressive Modulus, E_x: 2,692,793 psi

Ultimate Strain, ε_x: 0.014 in/in

Poisson's Ratio, ν_{xy}: 0.319

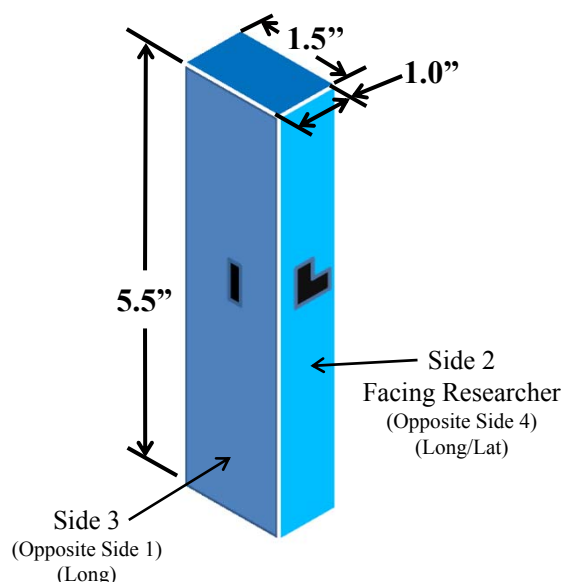
| Sample | Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|----------------|----------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| 1 | MAT1- CX-01-140-FY08 | 45,030 | 32,426 | 2,561,964 | 0.013 | 0.298 | Delam |
| 2 | MAT1- CX-02-140-FY08 | 49,697 | 34,093 | 3,005,779 | 0.011 | 0.389 | Delam |
| 3 | MAT1- CX-03-140-FY08 | 45,523 | 33,153 | 2,545,926 | 0.013 | 0.283 | Delam |
| 4 | MAT1- CX-04-140-FY08 | 45,358 | 33,033 | 2,785,286 | 0.012 | 0.380 | Delam |
| 5 | MAT1- CX-05-140-FY08 | 46,873 | 33,469 | 2,564,959 | 0.013 | 0.246 | Delam |
| Average | | 46,496 | 33,235 | 2,692,793 | 0.012 | 0.319 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See B-32 to B-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-01-140-FY08
 Test Date: 3/21/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 45,030 lbs
 Compressive Strength, SC_x : 32,426 psi
 Compressive Modulus, E_x : 2,561,964 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.298

Measured Specimen Dimensions:

Width, W: 0.99 in
 Thickness, H: 1.41 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 9,006 lbs
 50% Max Load: 22,515 lbs

PICTURE OF SPECIMEN PRE-TEST



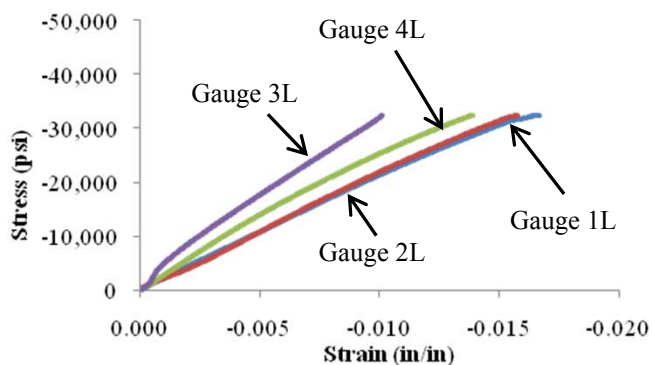
PICTURE OF SPECIMEN POST-TEST



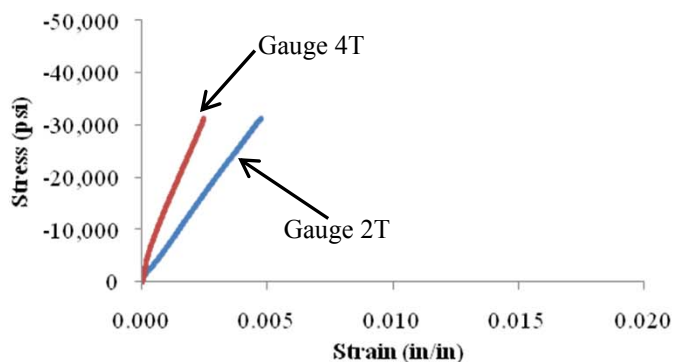
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0075 | -0.0030 | 2,133,549 | | | | |
| 2L | -0.0074 | -0.0032 | 2,322,294 | 2T | 0.0024 | 0.0010 | 0.339 |
| 3L | -0.0059 | -0.0023 | 2,660,312 | | | | |
| 4L | -0.0045 | -0.0014 | 3,131,701 | 4T | 0.0011 | 0.0003 | 0.257 |
| Average | | | 2,561,964 | | | | 0.298 |

Stress-Strain Curve 140_01_(08-01), Long



Stress-Strain Curve 140_01_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-02-140-FY08**
 Test Date: 3/21/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 49,697 lbs
 Compressive Strength, SC_x : 34,093 psi
 Compressive Modulus, E_x : 3,005,779 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.389

Measured Specimen Dimensions:

Width, W: 1.05 in
 Thickness, H: 1.39 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 9,939 lbs
 50% Max Load: 24,849 lbs

PICTURE OF SPECIMEN PRE-TEST



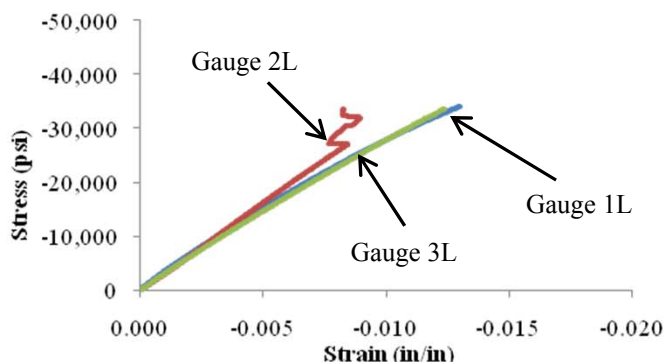
PICTURE OF SPECIMEN POST-TEST



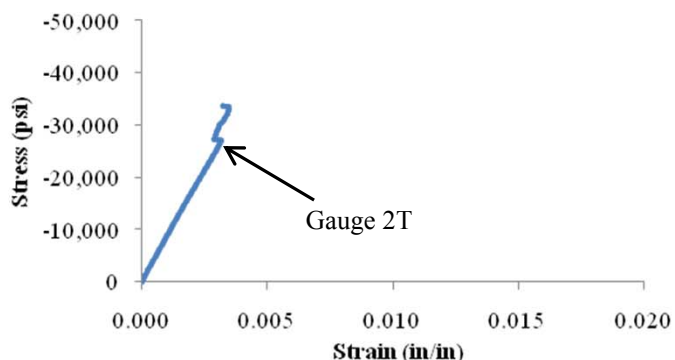
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0056 | -0.0021 | 2,863,935 | | | | |
| 2L | -0.0052 | -0.0022 | 3,329,684 | 2T | 0.0020 | 0.0008 | 0.389 |
| 3L | -0.0059 | -0.0023 | 2,823,719 | | | | |
| 4L | Lost Gauge | Lost Gauge | - | 4T | Lost Gauge | Lost Gauge | - |
| Average | | | 3,005,779 | | | | 0.389 |

Stress-Strain Curve 140_02_(08-01), Long



Stress-Strain Curve 140_02_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-03-140-FY08
 Test Date: 3/21/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 45,523 lbs
 Compressive Strength, SC_x : 33,153 psi
 Compressive Modulus, E_x : 2,545,926 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.283

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.38 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 9,105 lbs
 50% Max Load: 22,761 lbs

PICTURE OF SPECIMEN PRE-TEST



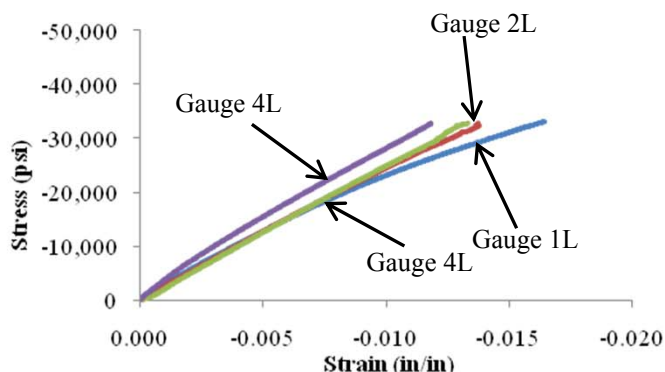
PICTURE OF SPECIMEN POST-TEST



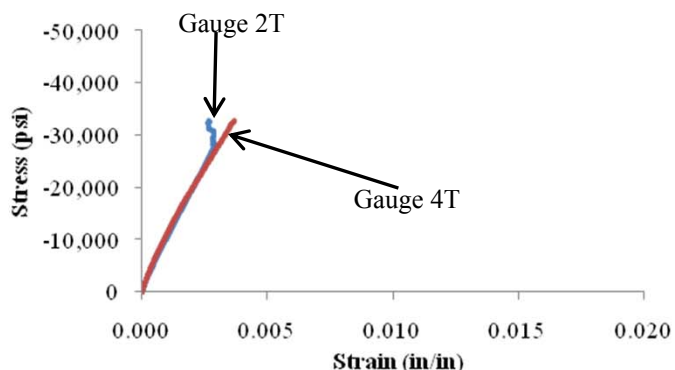
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0067 | -0.0024 | 2,331,883 | | | | |
| 2L | -0.0066 | -0.0026 | 2,496,700 | 2T | 0.0017 | 0.0006 | 0.268 |
| 3L | -0.0066 | -0.0027 | 2,557,339 | | | | |
| 4L | -0.0054 | -0.0019 | 2,797,783 | 4T | 0.0016 | 0.0005 | 0.297 |
| Average | | | 2,545,926 | | | | 0.283 |

Stress-Strain Curve 140_03_(08-01), Long



Stress-Strain Curve 140_03_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-04-140-FY08
 Test Date: 3/22/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 45,358 lbs
 Compressive Strength, SC_x : 33,033 psi
 Compressive Modulus, E_x : 2,785,286 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, v_{xy} : 0.380

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 1.38 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 9,072 lbs
 50% Max Load: 22,679 lbs

PICTURE OF SPECIMEN PRE-TEST



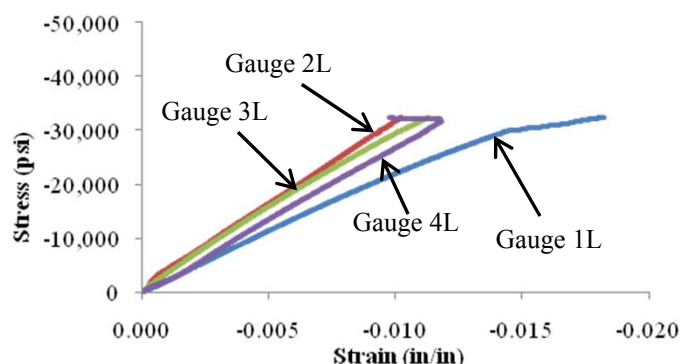
PICTURE OF SPECIMEN POST-TEST



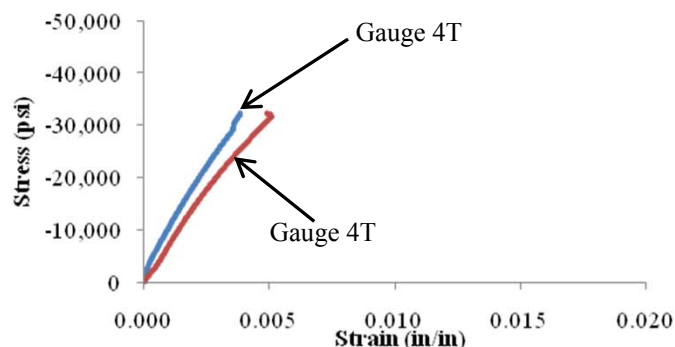
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|--------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio v_{xy} |
| 1L | -0.0073 | -0.0029 | 2,234,910 | | | | |
| 2L | -0.0050 | -0.0018 | 3,051,127 | 2T | 0.0017 | 0.0002 | 0.368 |
| 3L | -0.0052 | -0.0019 | 3,024,066 | | | | |
| 4L | -0.0061 | -0.0026 | 2,831,040 | 4T | 0.0023 | 0.0009 | 0.393 |
| Average | | | 2,785,286 | | | | 0.380 |

Stress-Strain Curve 140_04_(08-01), Long



Stress-Strain Curve 140_04_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-05-140-FY08
 Test Date: 3/22/2011
 Specimen Received: 2/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 46,873 lbs
 Compressive Strength, SC_x : 33,469 psi
 Compressive Modulus, E_x : 2,564,959 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.246

Measured Specimen Dimensions:

Width, W: 1.01 in
 Thickness, H: 1.39 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 9,375 lbs
 50% Max Load: 23,436 lbs

PICTURE OF SPECIMEN PRE-TEST



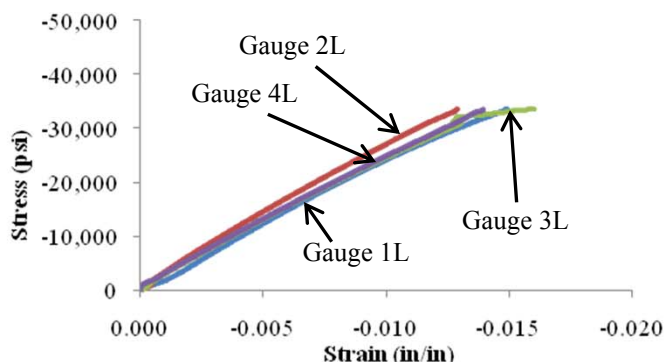
PICTURE OF SPECIMEN POST-TEST



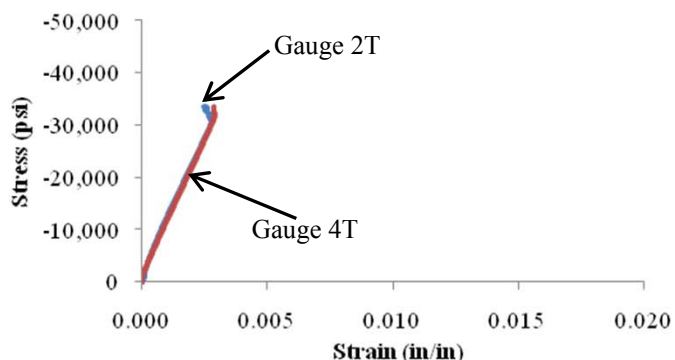
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio ν_{xy} |
| 1L | -0.0067 | -0.0029 | 2,599,898 | | | | |
| 2L | -0.0058 | -0.0021 | 2,708,174 | 2T | 0.0014 | 0.0005 | 0.255 |
| 3L | -0.0065 | -0.0024 | 2,480,872 | | | | |
| 4L | -0.0064 | -0.0024 | 2,470,891 | 4T | 0.0015 | 0.0005 | 0.237 |
| Average | | | 2,564,959 | | | | 0.246 |

Stress-Strain Curve 140_05_(08-01), Long



Stress-Strain Curve 140_05_(08-01), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXY-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 28,934 lbs

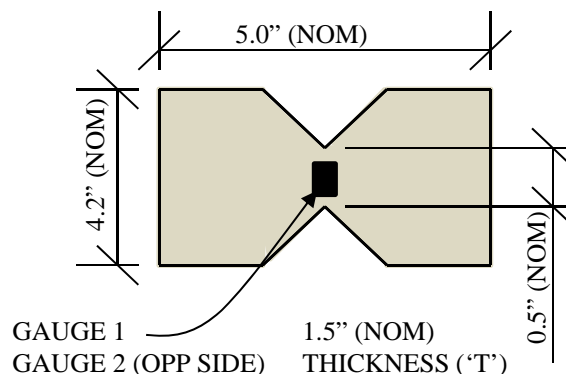
Shear Strength, S_{xy} : 37,620 psi

Shear Modulus, G_{xy} : 1,429,514 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT1-SXY-01-N40-FY08 | 28,512 | 37,996 | 1,494,954 | Shear |
| 2 | MAT1-SXY-02-N40-FY08 | 28,012 | 36,607 | 1,404,931 | Shear |
| 3 | MAT1-SXY-03-N40-FY08 | 28,871 | 37,930 | 1,478,355 | Shear |
| 4 | MAT1-SXY-04-N40-FY08 | 27,701 | 37,755 | 1,507,735 | Shear |
| 5 | MAT1-SXY-05-N40-FY08 | 28,875 | 37,814 | 1,261,596 | Shear |
| Average | | 28,934 | 37,620 | 1,429,514 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

FACING RESEARCHERS

Notes:

- 1) Individual specimen results are shown on Sheets B-38 to B-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-1-N40-FY08
 Test Date: 3/10/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 28,512 lbs
 Shear Stress, S_{xy} : 37,996 psi
 Shear Modulus, G_{xy} : 1,494,954 psi

Measured Specimen Dimensions:

Thickness, T : 1.34 in
 Notch Length, N : 0.56 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,702 lbs
 50% Max Load: 14,256 lbs

PICTURE OF SPECIMEN PRE-TEST



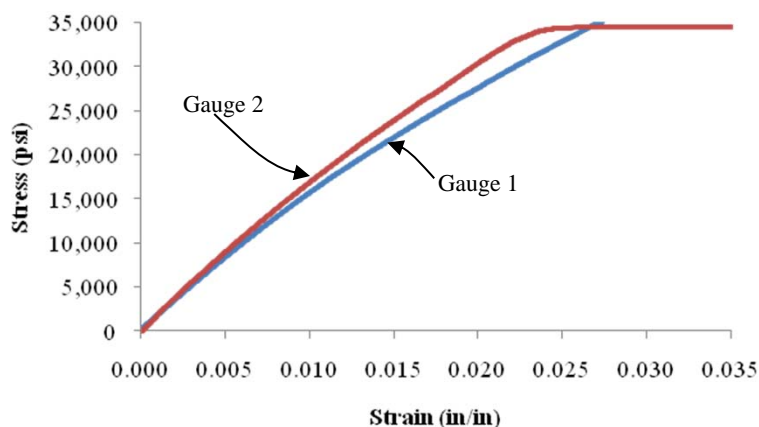
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0125 | 0.0045 | 1,419,251 |
| 2 | 0.0115 | 0.0042 | 1,570,657 |
| Average | | | 1,494,954 |

Stress-Strain Curve N40_1 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-2-N40-FY08
 Test Date: 3/11/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

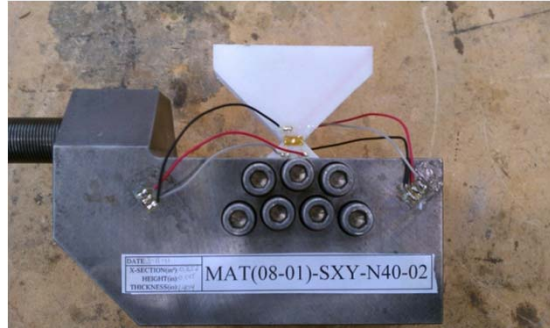
Average Material Properties:

Ultimate Load, P_{max} : 28,012 lbs
 Shear Stress, S_{xy} : 36,607 psi
 Shear Modulus, G_{xy} : 1,404,931 psi

Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,602 lbs
 50% Max Load: 14,006 lbs

PICTURE OF SPECIMEN PRE-TEST



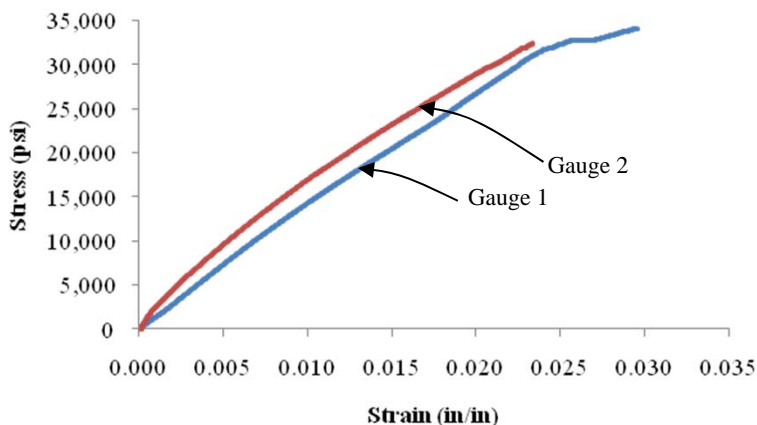
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0132 | 0.0050 | 1,335,189 |
| 2 | 0.0111 | 0.0036 | 1,474,672 |
| Average | | | 1,404,931 |

Stress-Strain Curve N40_2 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-3-N40-FY08
 Test Date: 3/11/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 27,871 lbs
 Shear Stress, S_{xy} : 37,930 psi
 Shear Modulus, G_{xy} : 1,478,355 psi

Measured Specimen Dimensions:

Thickness, T : 1.34 in
 Notch Length, N : 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,574 lbs
 50% Max Load: 13,936 lbs

PICTURE OF SPECIMEN PRE-TEST



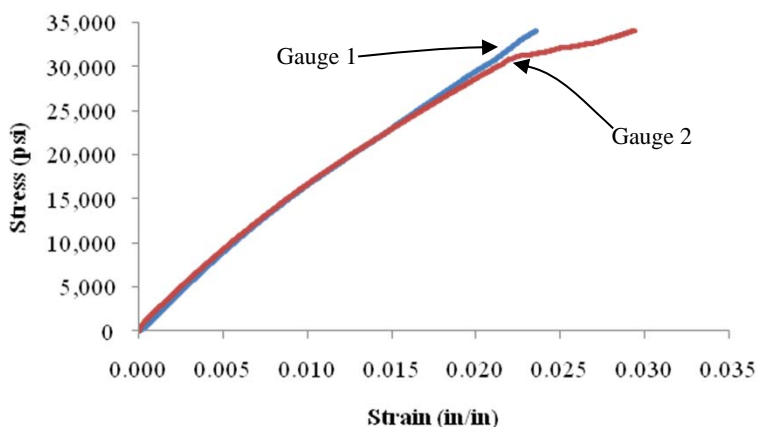
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0118 | 0.0042 | 1,493,693 |
| 2 | 0.0117 | 0.0040 | 1,463,018 |
| Average | | | 1,478,355 |

Stress-Strain Curve N40_3 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-4-N40-FY08
 Test Date: 3/11/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 27,701 lbs
 Shear Stress, S_{xy} : 37,755 psi
 Shear Modulus, G_{xy} : 1,507,735 psi

Measured Specimen Dimensions:

Thickness, T : 1.33 in
 Notch Length, N : 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,540 lbs
 50% Max Load: 13,850 lbs

PICTURE OF SPECIMEN PRE-TEST



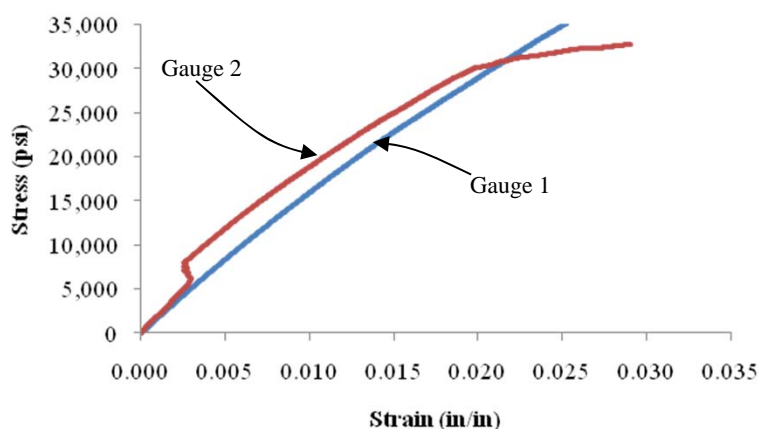
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0121 | 0.0045 | 1,493,781 |
| 2 | 0.0100 | 0.0026 | 1,521,688 |
| Average | | | 1,507,735 |

Stress-Strain Curve N40_4(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-5-N40-FY08
 Test Date: 3/11/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 28,875 lbs
 Shear Stress, S_{xy} : 37,814 psi
 Shear Modulus, G_{xy} : 1,261,596 psi

Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 5,775 lbs
 50% Max Load: 14,438 lbs

PICTURE OF SPECIMEN PRE-TEST



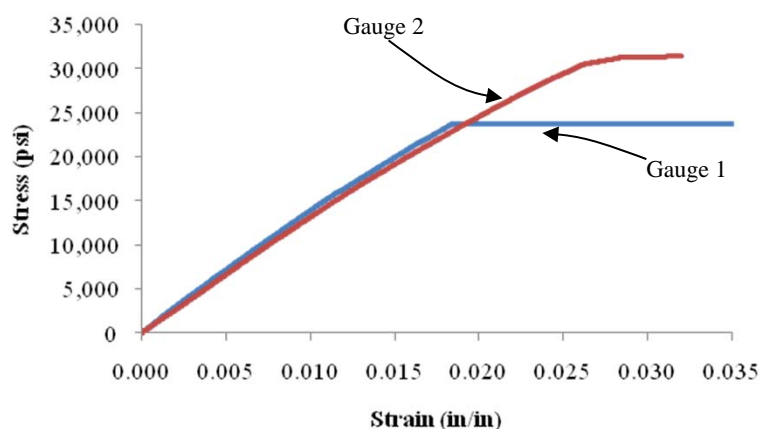
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0141 | 0.0052 | 1,278,467 |
| 2 | 0.0148 | 0.0057 | 1,244,726 |
| Average | | | 1,261,596 |

Stress-Strain Curve N40_5 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXY-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 23,141 lbs

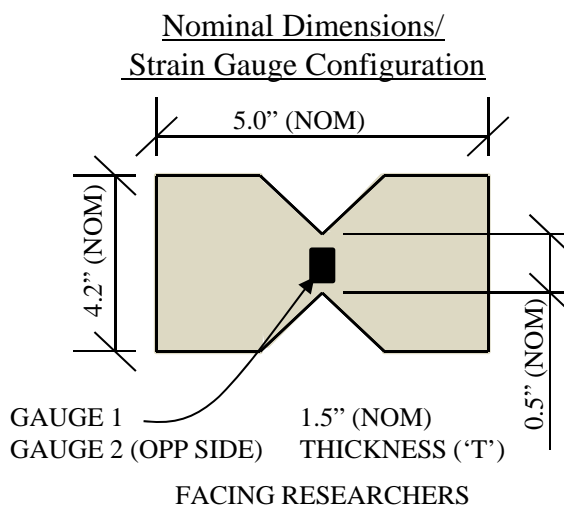
Shear Strength, S_{xy} : 31,056 psi

Shear Modulus, G_{xy} : 1,313,712 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|--------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT1-SXY-1-70-FY08 | 22,709 | 31,584 | 1,448,831 | Shear |
| 2 | MAT1-SXY-2-70-FY08 | 23,988 | 30,996 | 1,393,763 | Shear |
| 3 | MAT1-SXY-3-70-FY08 | 22,541 | 30,160 | 1,279,992 | Shear |
| 4 | MAT1-SXY-4-70-FY08 | 22,932 | 30,253 | 1,087,050 | Shear |
| 5 | MAT1-SXY-5-70-FY08 | 23,537 | 32,286 | 1,358,924 | Shear |
| Average | | 23,141 | 31,056 | 1,313,712 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets B-44 to B-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-1-70-FY08
 Test Date: 3/4/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 22,709 lbs
 Shear Stress, S_{xy} : 31,584 psi
 Shear Modulus, G_{xy} : 1,448,831 psi

Measured Specimen Dimensions:

Thickness, T: 1.34 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,542 lbs
 50% Max Load : 11,355 lbs

PICTURE OF SPECIMEN PRE-TEST



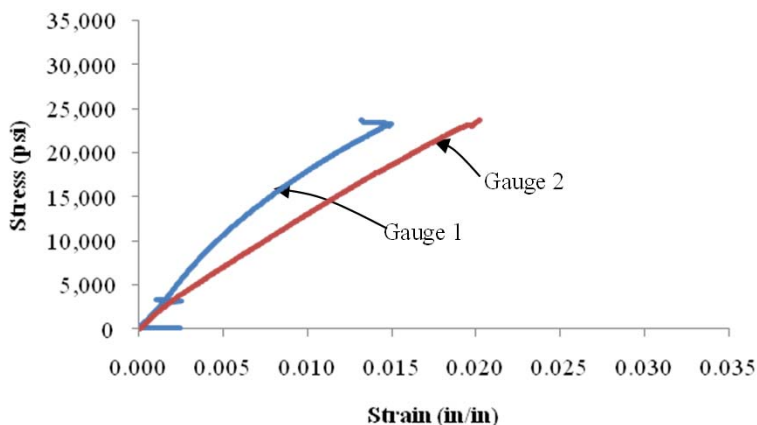
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0083 | 0.0028 | 1,710,406 |
| 2 | 0.0124 | 0.0044 | 1,187,256 |
| Average | | | 1,448,831 |

Stress-Strain Curve 70_1 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-2-70-FY08
 Test Date: 3/7/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

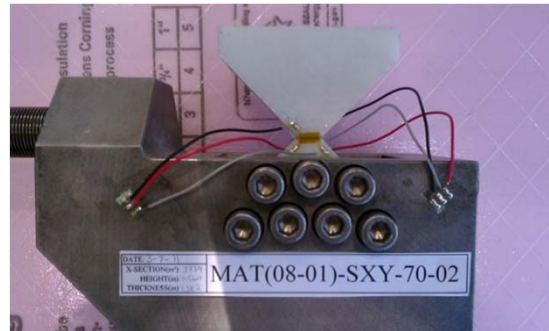
Average Material Properties:

Ultimate Load, P_{max} : 23,988 lbs
 Shear Stress, S_{xy} : 30,996 psi
 Shear Modulus, G_{xy} : 1,393,763 psi

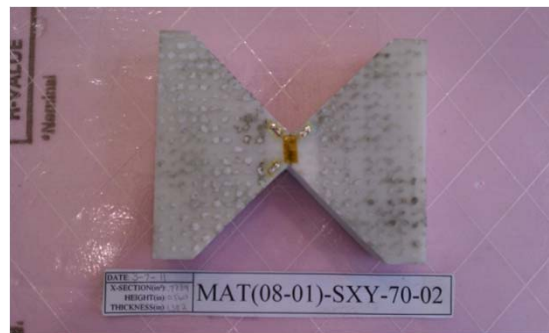
Measured Specimen Dimensions:

Thickness, T: 1.38 in
 Notch Length, N: 0.56 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,798 lbs
 50% Max Load : 11,994 lbs

PICTURE OF SPECIMEN PRE-TEST



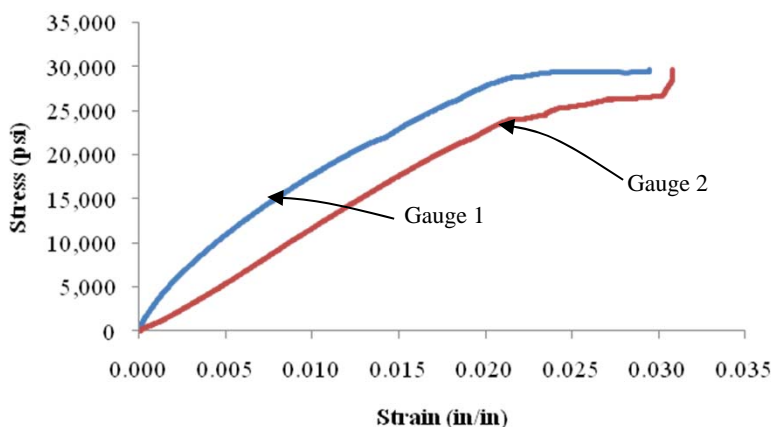
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0082 | 0.0023 | 1,550,736 |
| 2 | 0.0132 | 0.0057 | 1,236,790 |
| Average | | | 1,393,763 |

Stress-Strain Curve 70_2 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-3-70-FY08
 Test Date: 3/7/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 22,541 lbs
 Shear Stress, S_{xy} : 30,160 psi
 Shear Modulus, G_{xy} : 1,279,992 psi

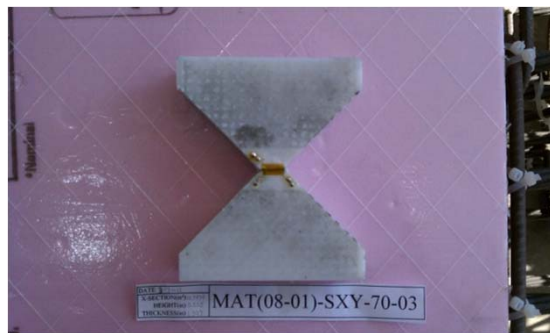
Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,508 lbs
 50% Max Load: 11,271 lbs

PICTURE OF SPECIMEN PRE-TEST



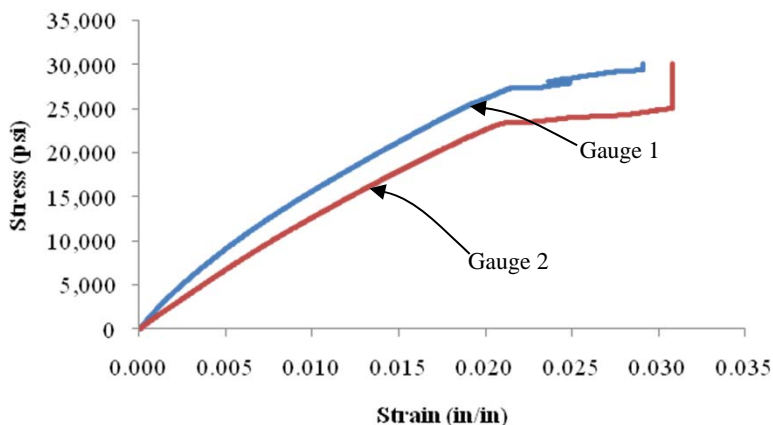
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0030 | 0.0030 | 1,398,241 |
| 2 | 0.0122 | 0.0045 | 1,161,743 |
| Average | | | 1,279,992 |

Stress-Strain Curve 70_3 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-4-70-FY08
 Test Date: 3/7/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 22,932 lbs
 Shear Stress, S_{xy} : 30,253 psi
 Shear Modulus, G_{xy} : 1,087,050 psi

Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,586 lbs
 50% Max Load: 11,466 lbs

PICTURE OF SPECIMEN PRE-TEST



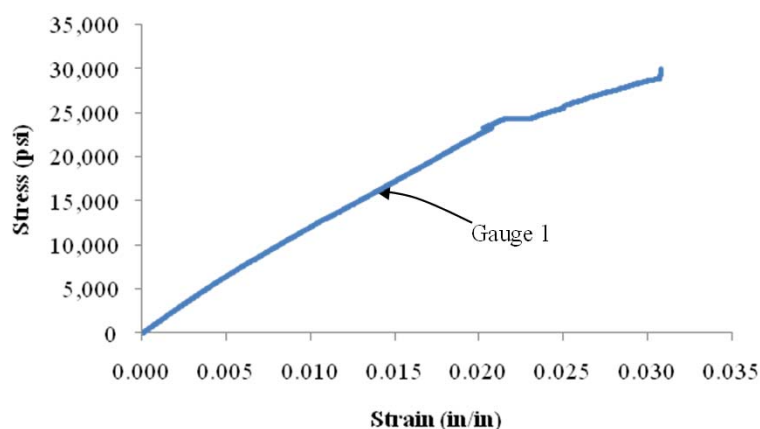
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0130 | 0.0047 | 1,087,050 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 1,087,050 |

Stress-Strain Curve 70_4(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-5-70-FY08
 Test Date: 3/7/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 23,537 lbs
 Shear Stress, S_{xy} : 32,286 psi
 Shear Modulus, G_{xy} : 1,358,924 psi

Measured Specimen Dimensions:

Thickness, T: 1.35 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,707 lbs
 50% Max Load: 11,768 lbs

PICTURE OF SPECIMEN PRE-TEST



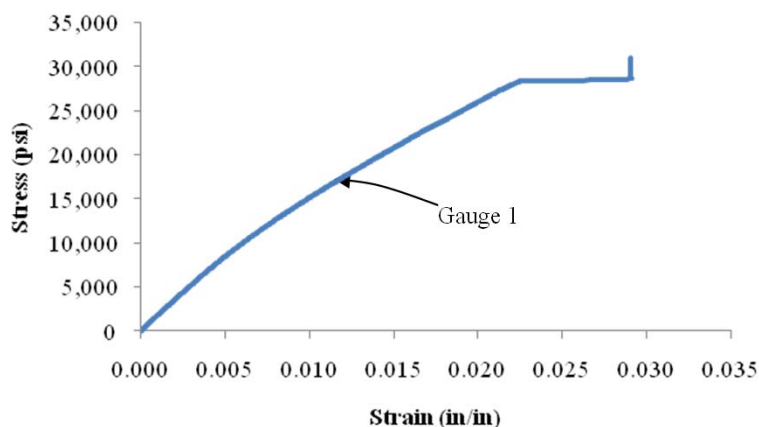
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0108 | 0.0037 | 1,358,924 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 1,358,924 |

Stress-Strain Curve 70_5(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXY-140-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 20,784 lbs

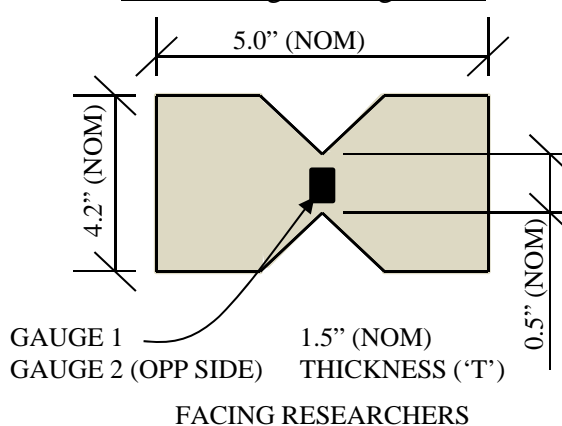
Shear Strength, S_{xy} : 27,806 psi

Shear Modulus, G_{xy} : 1,221,689 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT1-SXY-1-140-FY08 | 20,580 | 28,254 | 1,231,089 | Shear |
| 2 | MAT1-SXY-2-140-FY08 | 20,451 | 26,995 | 1,239,937 | Shear |
| 3 | MAT1-SXY-3-140-FY08 | 21,532 | 28,380 | 1,249,767 | Shear |
| 4 | MAT1-SXY-4-140-FY08 | 20,520 | 28,295 | 1,235,632 | Shear |
| 5 | MAT1-SXY-5-140-FY08 | 20,839 | 27,120 | 1,152,018 | Shear |
| Average | | 20,784 | 27,809 | 1,221,689 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets B-50 to B-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-1-140-FY08
 Test Date: 3/8/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 20,580 lbs
 Shear Stress, S_{xy} : 28,254 psi
 Shear Modulus, G_{xy} : 1,231,089 psi

Measured Specimen Dimensions:

Thickness, T: 1.34 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,116 lbs
 50% Max Load: 10,290 lbs

PICTURE OF SPECIMEN PRE-TEST



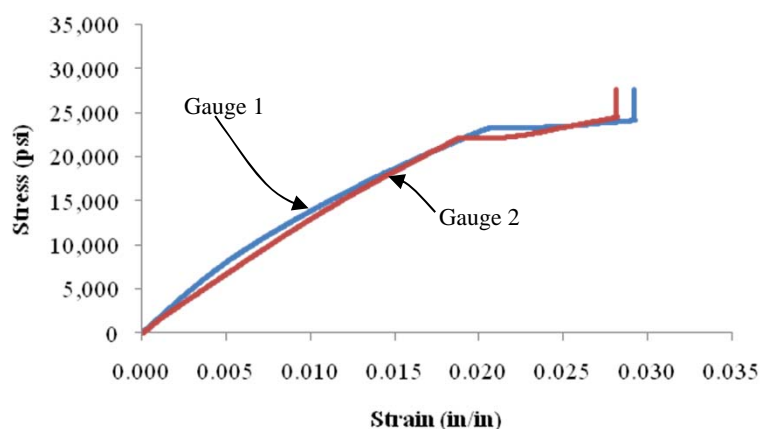
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0103 | 0.0034 | 1,226,553 |
| 2 | 0.0110 | 0.0042 | 1,235,625 |
| Average | | | 1,231,089 |

Stress-Strain Curve 140_1 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-2-140-FY08
 Test Date: 3/8/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

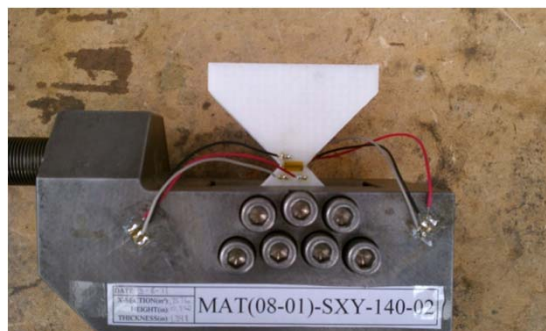
Average Material Properties:

Ultimate Load, P_{max} : 20,451 lbs
 Shear Stress, S_{xy} : 26,995 psi
 Shear Modulus, G_{xy} : 1,239,937 psi

Measured Specimen Dimensions:

Thickness, T: 1.35 in
 Notch Length, N: 0.56 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,090 lbs
 50% Max Load: 10,226 lbs

PICTURE OF SPECIMEN PRE-TEST



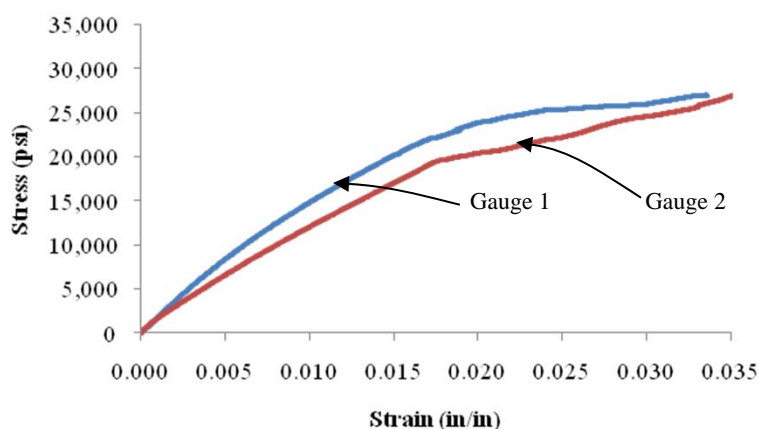
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0089 | 0.0031 | 1,392,426 |
| 2 | 0.0114 | 0.0040 | 1,087,448 |
| Average | | | 1,239,937 |

Stress-Strain Curve 140_2 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-3-140-FY08
 Test Date: 3/9/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 21,532 lbs
 Shear Stress, S_{xy} : 28,380 psi
 Shear Modulus, G_{xy} : 1,249,767 psi

Measured Specimen Dimensions:

Thickness, T: 1.41 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,306 lbs
 50% Max Load: 10,766 lbs

PICTURE OF SPECIMEN PRE-TEST



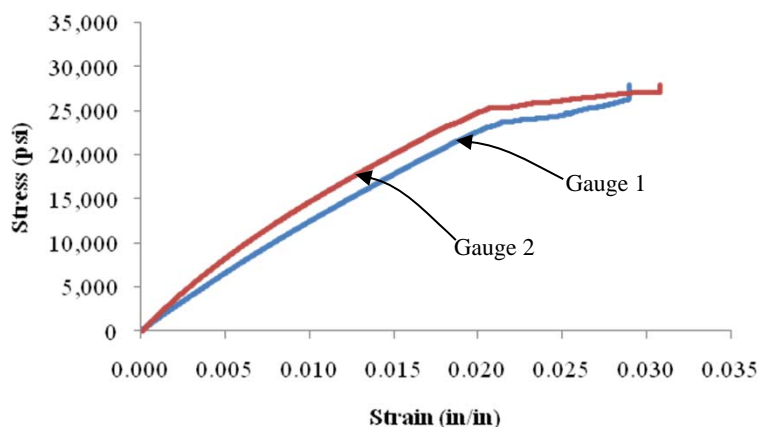
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0116 | 0.0042 | 1,156,097 |
| 2 | 0.0096 | 0.0033 | 1,343,438 |
| Average | | | 1,249,767 |

Stress-Strain Curve 140_3 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-4-140-FY08
 Test Date: 3/9/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

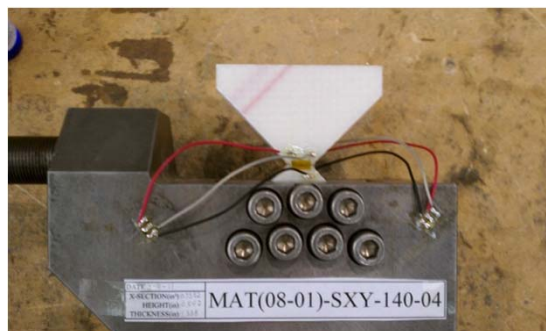
Average Material Properties:

Ultimate Load, P_{max} : 20,520 lbs
 Shear Stress, S_{xy} : 28,295 psi
 Shear Modulus, G_{xy} : 1,235,632 psi

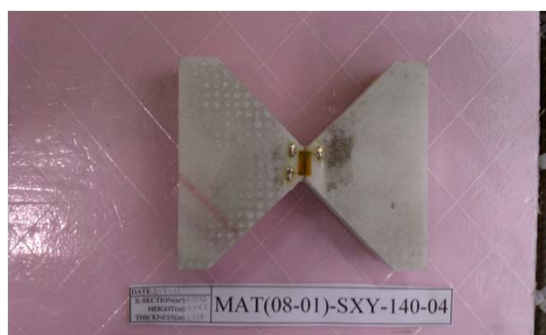
Measured Specimen Dimensions:

Thickness, T: 1.34 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,104 lbs
 50% Max Load: 10,260 lbs

PICTURE OF SPECIMEN PRE-TEST



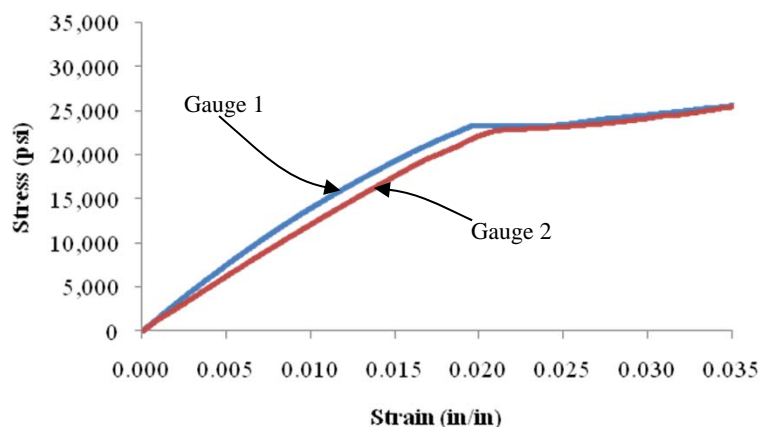
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0102 | 0.0037 | 1,309,723 |
| 2 | 0.0119 | 0.0046 | 1,161,541 |
| Average | | | 1,235,632 |

Stress-Strain Curve 140_4 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-5-140-FY08
 Test Date: 3/9/11
 Specimen Received: 2/17/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 20,839 lbs
 Shear Stress, S_{xy} : 27,120 psi
 Shear Modulus, G_{xy} : 1,152,018 psi

Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,168 lbs
 50% Max Load: 10,419 lbs

PICTURE OF SPECIMEN PRE-TEST



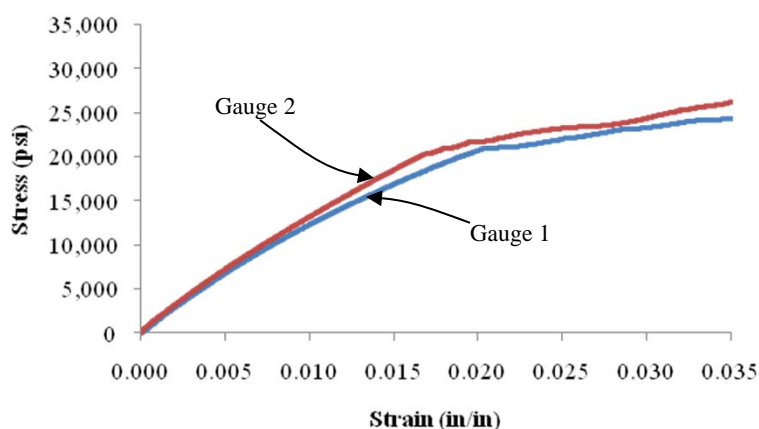
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|----------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Modulus (G_{xy}) (psi) |
| 1 | 0.0113 | 0.0039 | 1,099,709 |
| 2 | 0.0103 | 0.0036 | 1,204,327 |
| Average | | | 1,152,018 |

Stress-Strain Curve 140_5 (08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

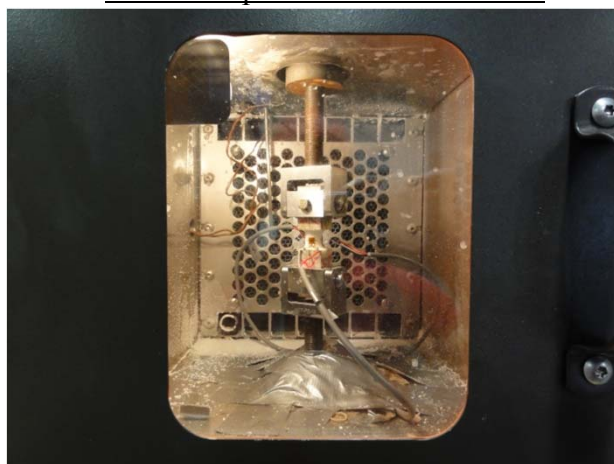
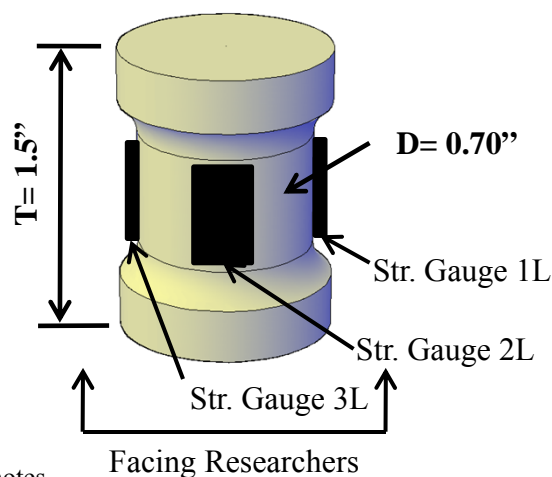
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TZ-N40-FY08
Material: Epoxy Resin SC-15, S2 Glass
Nominal Temperature: -40°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 1,951 lbs
 Tensile Strength, ST_z : 5,028 psi
 Tensile Modulus, E_z : 1,465,000 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT1-TZ-1-N40-FY08 | 2,088 | 5,411 | 1,506,148 | Rupture |
| MAT1-TZ-2-N40-FY08 | 1,921 | 4,865 | 1,563,720 | Rupture |
| MAT1-TZ-3-N40-FY08 | 1,873 | 4,826 | 1,474,614 | Rupture |
| MAT1-TZ-4-N40-FY08 | 1,790 | 4,639 | 1,396,301 | Rupture |
| MAT1-TZ-5-N40-FY08 | 2,083 | 5,398 | 1,384,216 | Rupture |
| Average | 1,951 | 5,028 | 1,465,000 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference B-56 to B-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-N40-FY08**
 Test Date: 8/25/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 5,411 psi
 Tensile Modulus, E_z : 1,506,148 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,706 psi
 20% Max Stress: 1,082 psi

PICTURE OF SPECIMEN PRE-TEST



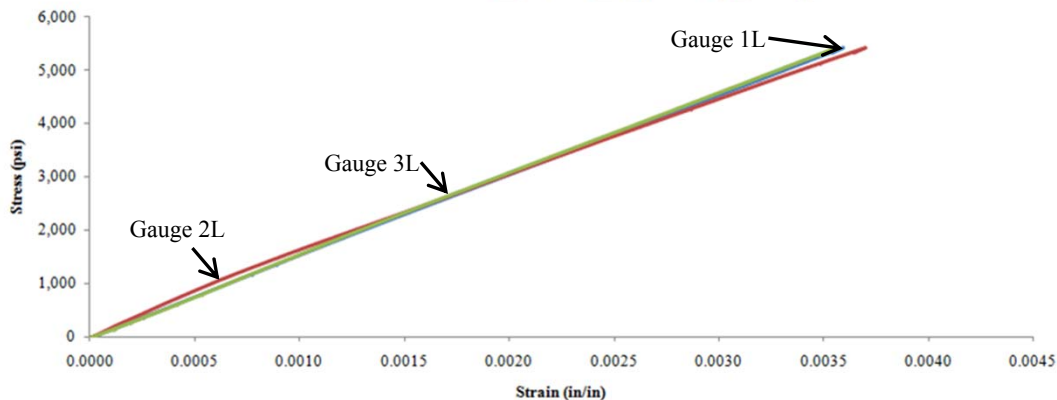
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001774 | 0.000710 | 1,525,951 |
| 2L | 0.001761 | 0.000629 | 1,433,067 |
| 3L | 0.001752 | 0.000711 | 1,559,424 |
| Average | | | 1,506,148 |

Stress-Strain Curve_N40°F_1_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-N40-FY08**
 Test Date: 8/25/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

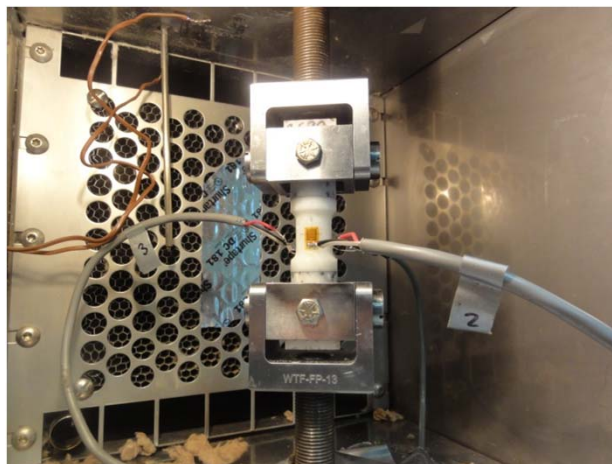
Average Material Properties:

Tensile Strength, ST_z : 4,865 psi
 Tensile Modulus, E_z : 1,563,720 psi

Measured Specimen Dimensions:

Diameter, D: 0.709 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,432 psi
 20% Max Stress: 973 psi

PICTURE OF SPECIMEN PRE-TEST



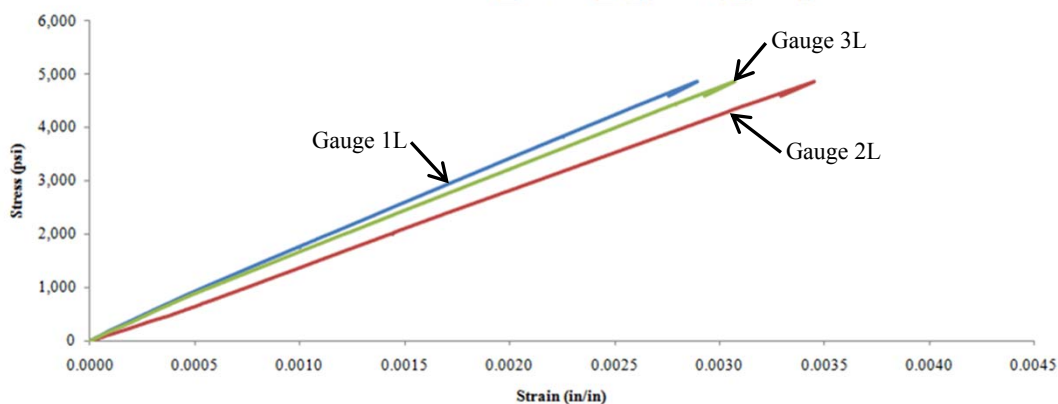
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001398 | 0.000523 | 1,667,806 |
| 2L | 0.001722 | 0.000723 | 1,461,433 |
| 3L | 0.001486 | 0.000552 | 1,561,920 |
| Average | | | 1,563,720 |

Stress-Strain Curve_N40°F_2_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-N40-FY08**
 Test Date: 8/29/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

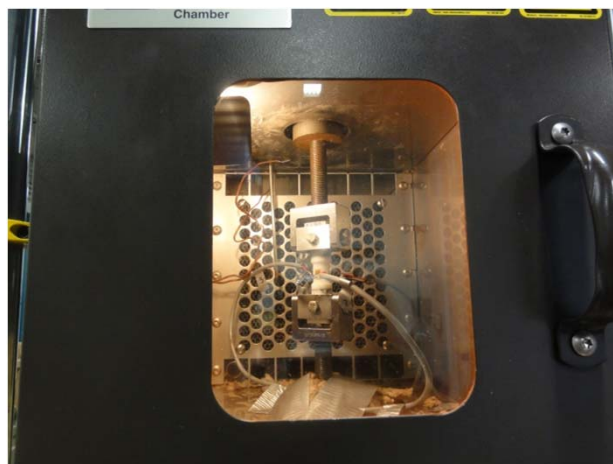
Average Material Properties:

Tensile Strength, ST_z : 4,826 psi
 Tensile Modulus, E_z : 1,474,614 psi

Measured Specimen Dimensions:

Diameter, D: 0.703 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,413 psi
 20% Max Stress: 965 psi

PICTURE OF SPECIMEN PRE-TEST



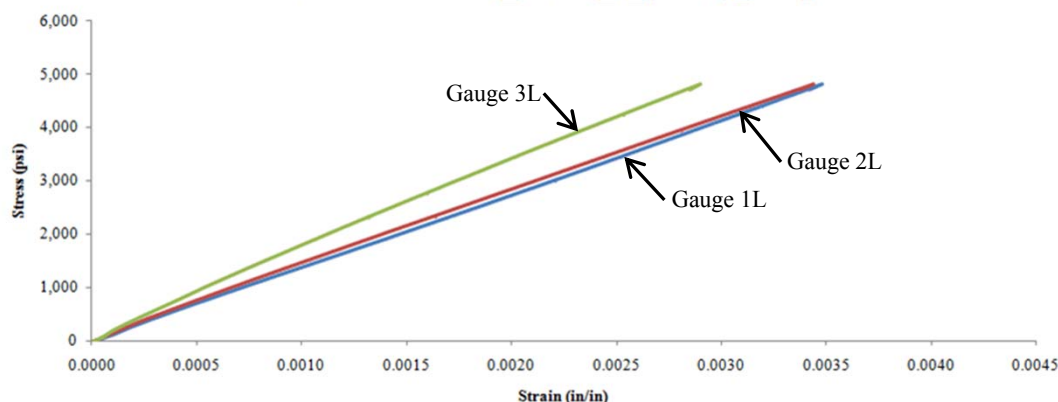
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001762 | 0.000684 | 1,342,419 |
| 2L | 0.001678 | 0.000634 | 1,386,640 |
| 3L | 0.001366 | 0.000512 | 1,694,783 |
| Average | | | 1,474,614 |

Stress-Strain Curve_N40°F_3_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-N40-FY08**
 Test Date: 8/29/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,639 psi
 Tensile Modulus, E_z : 1,396,301 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,319 psi
 20% Max Stress: 928 psi

PICTURE OF SPECIMEN PRE-TEST



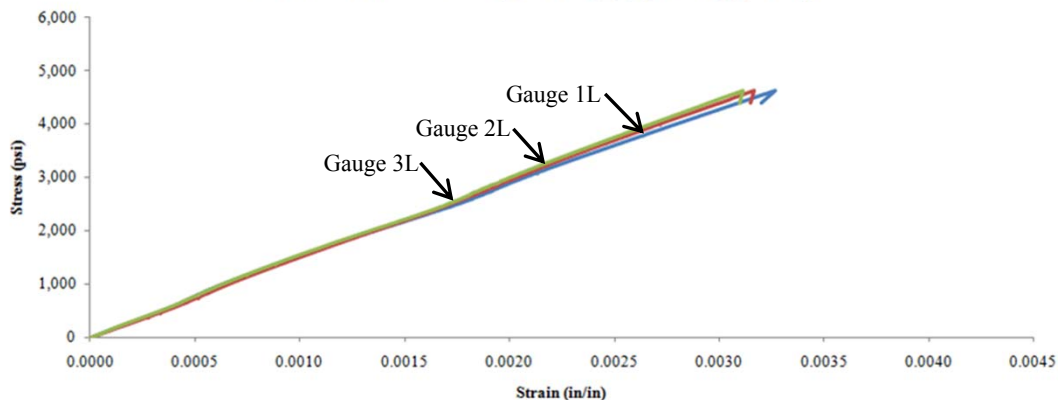
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001607 | 0.000583 | 1,359,026 |
| 2L | 0.001591 | 0.000614 | 1,423,934 |
| 3L | 0.001573 | 0.000583 | 1,405,942 |
| Average | | | 1,396,301 |

Stress-Strain Curve_N40°F_4_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-N40-FY08**
 Test Date: 8/29/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

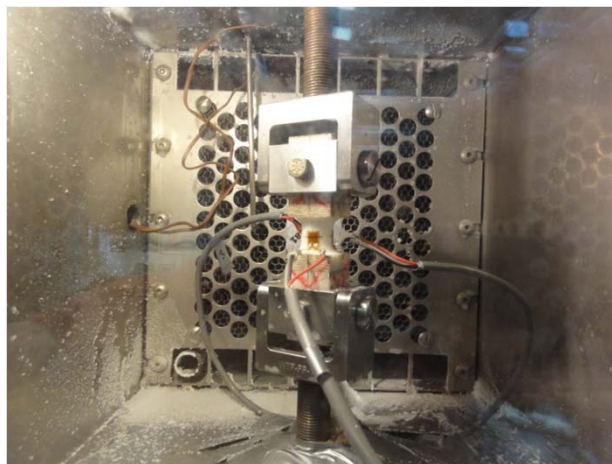
Average Material Properties:

Tensile Strength, ST_z : 5,398 psi
 Tensile Modulus, E_z : 1,384,216 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,699 psi
 20% Max Stress: 1,080 psi

PICTURE OF SPECIMEN PRE-TEST



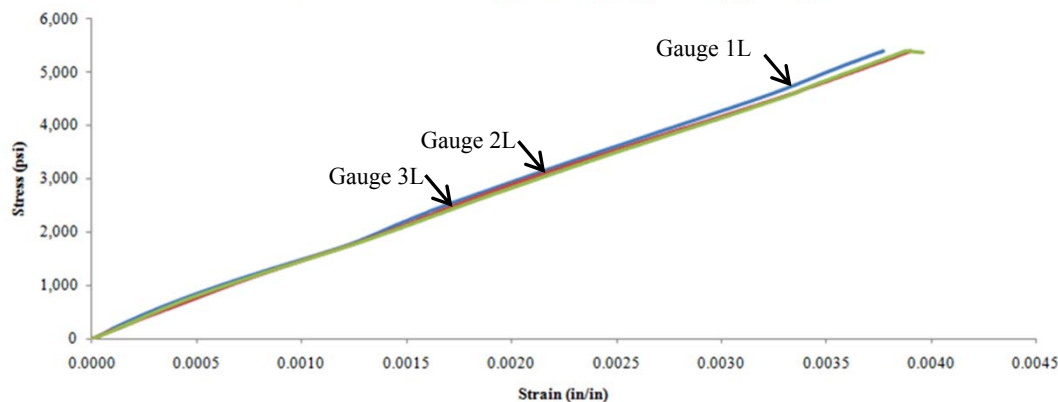
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001820 | 0.000666 | 1,402,588 |
| 2L | 0.001859 | 0.000707 | 1,405,859 |
| 3L | 0.001899 | 0.000694 | 1,344,201 |
| Average | | | 1,384,216 |

Stress-Strain Curve_N40°F_5_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

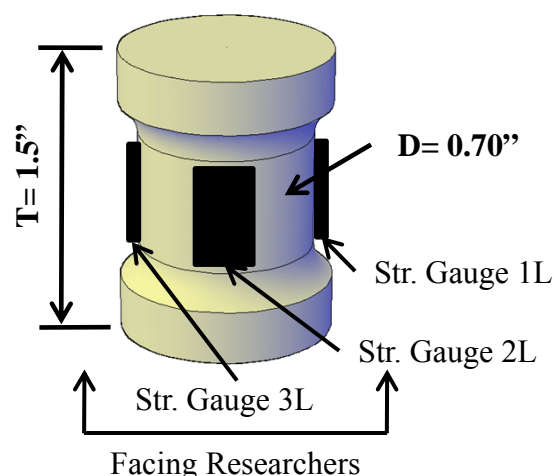
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TZ-70-FY08
Material: Epoxy Resin SC-15, S2 Glass
Nominal Temperature: 70°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 1,672 lbs
 Tensile Strength, ST_z : 4,347 psi
 Tensile Modulus, E_z : 1,424,406 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT1-TZ-1-70-FY08 | 1,589 | 4,152 | 1,418,257 | Rupture |
| MAT1-TZ-2-70-FY08 | 1,719 | 4,466 | 1,472,012 | Rupture |
| MAT1-TZ-3-70-FY08 | 1,724 | 4,466 | 1,497,941 | Rupture |
| MAT1-TZ-4-70-FY08 | 1,701 | 4,421 | 1,400,618 | Rupture |
| MAT1-TZ-5-70-FY08 | 1,629 | 4,232 | 1,333,203 | Rupture |
| Average | 1,672 | 4,347 | 1,424,406 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference B-62 to B-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-70-FY08**
 Test Date: 8/25/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,152 psi
 Tensile Modulus, E_z : 1,418,257 psi

Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,076 psi
 20% Max Stress: 830 psi

PICTURE OF SPECIMEN PRE-TEST



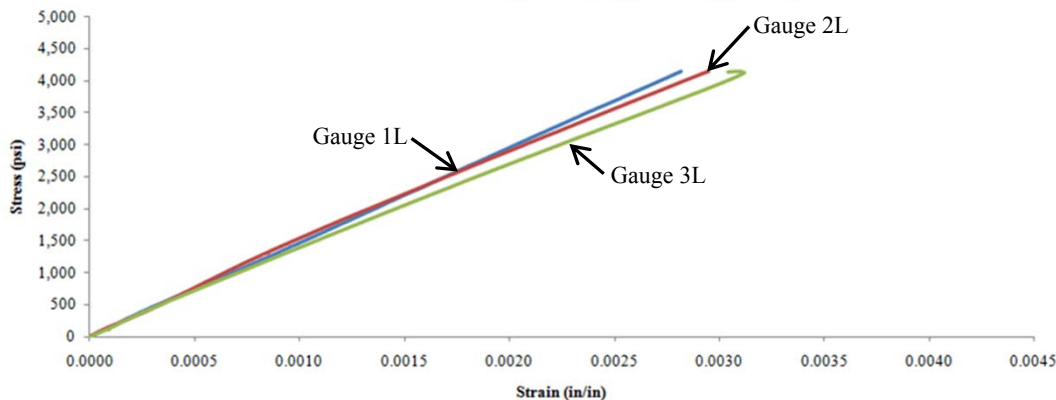
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001404 | 0.000549 | 1,457,995 |
| 2L | 0.001383 | 0.000533 | 1,466,063 |
| 3L | 0.001512 | 0.000576 | 1,330,713 |
| Average | | | 1,418,257 |

Stress-Strain Curve_70°F_1_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-70-FY08**
 Test Date: 8/26/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,466 psi
 Tensile Modulus, E_z : 1,472,012 psi

Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,233 psi
 20% Max Stress: 893 psi

PICTURE OF SPECIMEN PRE-TEST



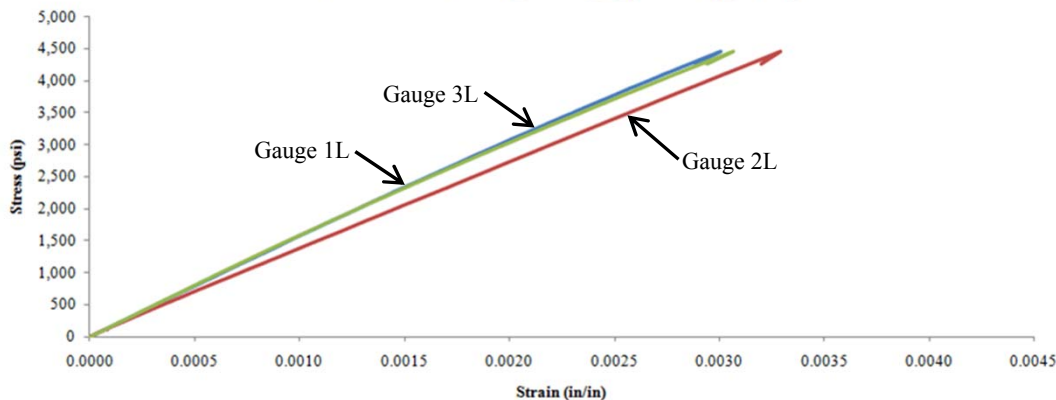
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001428 | 0.000561 | 1,546,167 |
| 2L | 0.001626 | 0.000633 | 1,349,236 |
| 3L | 0.001434 | 0.000553 | 1,520,633 |
| Average | | | 1,472,012 |

Stress-Strain Curve_70°F_2_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-70-FY08**
 Test Date: 8/26/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,466 psi
 Tensile Modulus, E_z : 1,497,941 psi

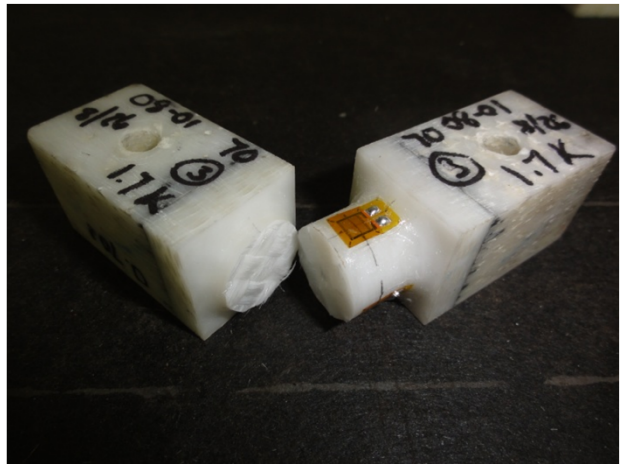
Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,233 psi
 20% Max Stress: 893 psi

PICTURE OF SPECIMEN PRE-TEST



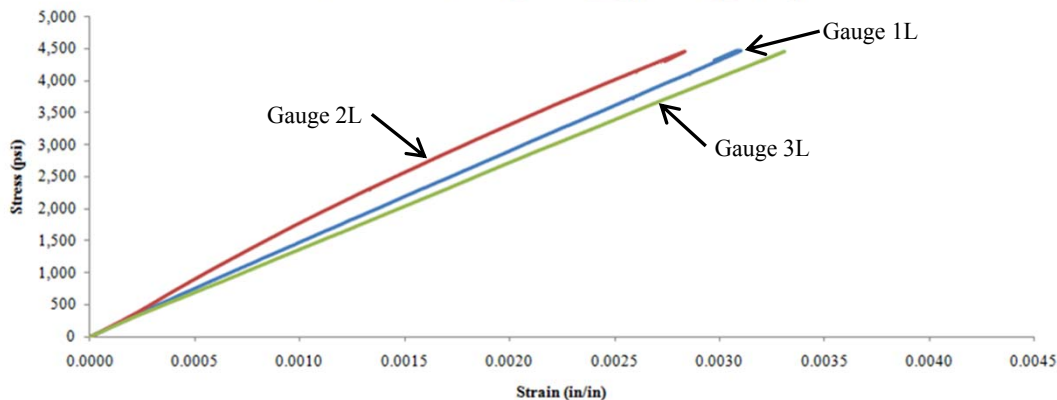
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001527 | 0.000592 | 1,432,385 |
| 2L | 0.001276 | 0.000492 | 1,708,395 |
| 3L | 0.001638 | 0.000647 | 1,353,042 |
| Average | | | 1,497,941 |

Stress-Strain Curve_70°F_3_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-70-FY08**
 Test Date: 8/26/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

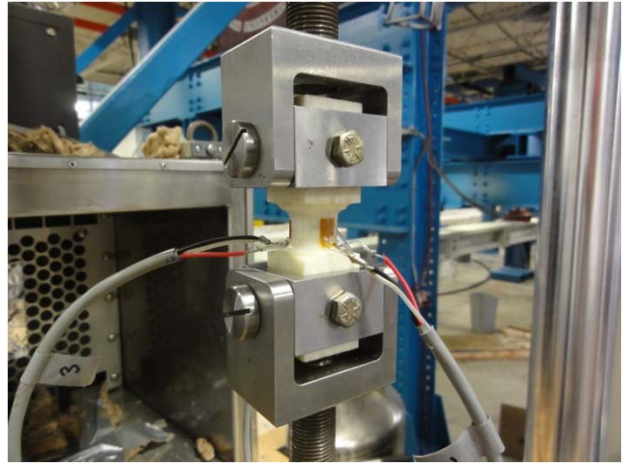
Average Material Properties:

Tensile Strength, ST_z : 4,498 psi
 Tensile Modulus, E_z : 1,424,941 psi

Measured Specimen Dimensions:

Diameter, D: 0.694 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,249 psi
 20% Max Stress: 900 psi

PICTURE OF SPECIMEN PRE-TEST



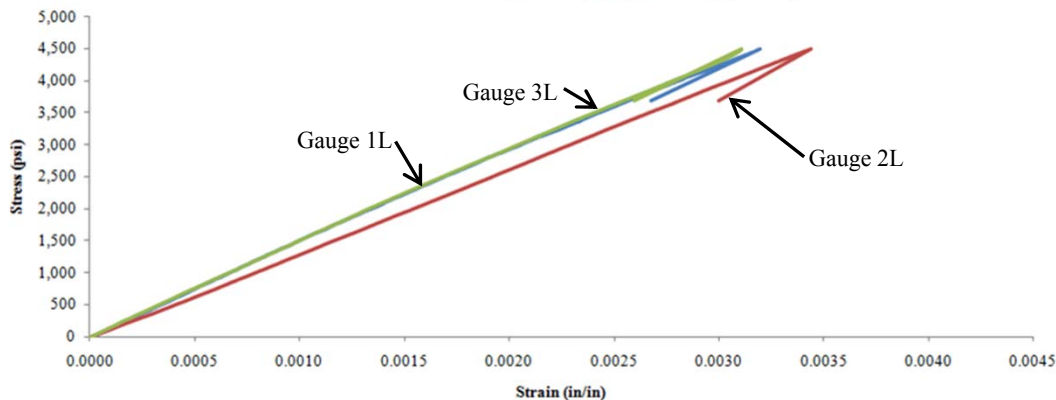
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001514 | 0.000596 | 1,469,724 |
| 2L | 0.001730 | 0.000711 | 1,323,817 |
| 3L | 0.001500 | 0.000589 | 1,481,282 |
| Average | | | 1,424,941 |

Stress-Strain Curve_70°F_4_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-70-FY08**
 Test Date: 8/26/2011
 Specimen Received: 8/16/2011
 Properties Measured: ST_z , E_z

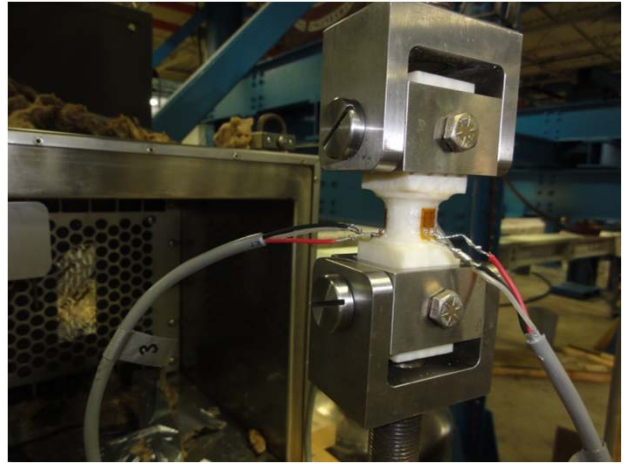
Average Material Properties:

Tensile Strength, ST_z : 4,232 psi
 Tensile Modulus, E_z : 1,333,203 psi

Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,116 psi
 20% Max Stress: 846 psi

PICTURE OF SPECIMEN PRE-TEST



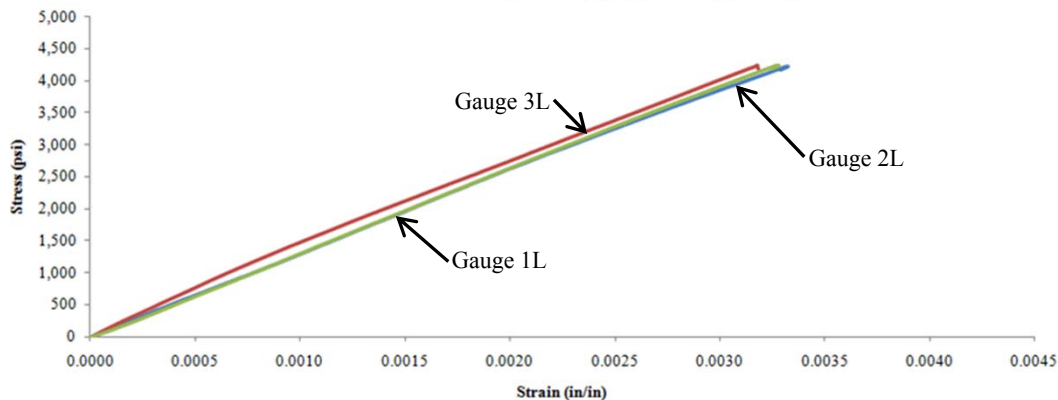
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001609 | 0.000649 | 1,322,692 |
| 2L | 0.001499 | 0.000552 | 1,340,511 |
| 3L | 0.001611 | 0.000661 | 1,336,405 |
| Average | | | 1,333,203 |

Stress-Strain Curve_70°F_5_(08-01)_Long



Engineering Test notes:

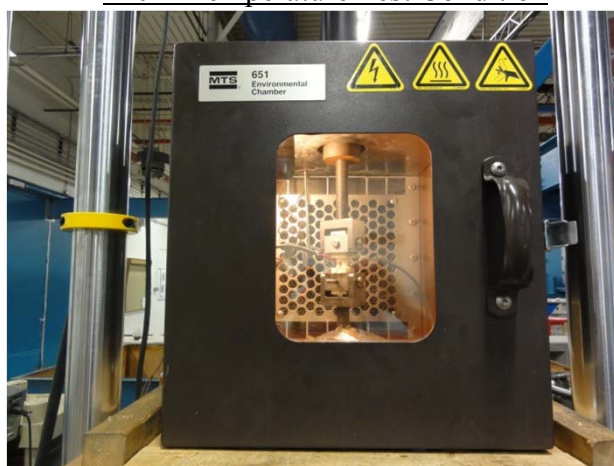
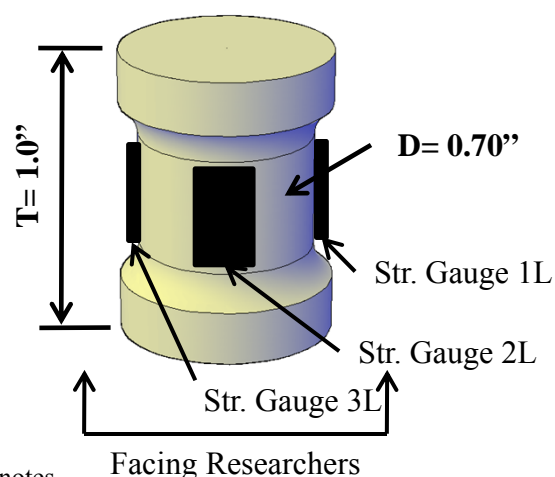
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT1-TZ-140-FY08**Material:** SC-15, S2 Glass**Nominal Temperature:** 140°F**Properties Measured:** ST_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 1,485 lbs**Tensile Strength, ST_z :** 3,888 psi**Tensile Modulus, E_z :** 1,106,657 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT1-TZ-1-140-FY08 | 1,538 | 3,917 | 1,185,494 | Rupture |
| MAT1-TZ-2-140-FY08 | 1,525 | 3,985 | 1,124,261 | Rupture |
| MAT1-TZ-3-140-FY08 | 1,481 | 3,960 | 1,018,821 | Rupture |
| MAT1-TZ-4-140-FY08 | 1,448 | 3,720 | 1,075,972 | Rupture |
| MAT1-TZ-5-140-FY08 | 1,434 | 3,856 | 1,128,738 | Rupture |
| Average | 1,485 | 3,888 | 1,106,657 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference B-68 to B-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-140-FY08**
 Test Date: 8/26/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,917 psi
 Tensile Modulus, E_z : 1,185,494 psi

Measured Specimen Dimensions:

Diameter, D: 0.707 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,959 psi
 20% Max Stress: 783 psi

PICTURE OF SPECIMEN PRE-TEST



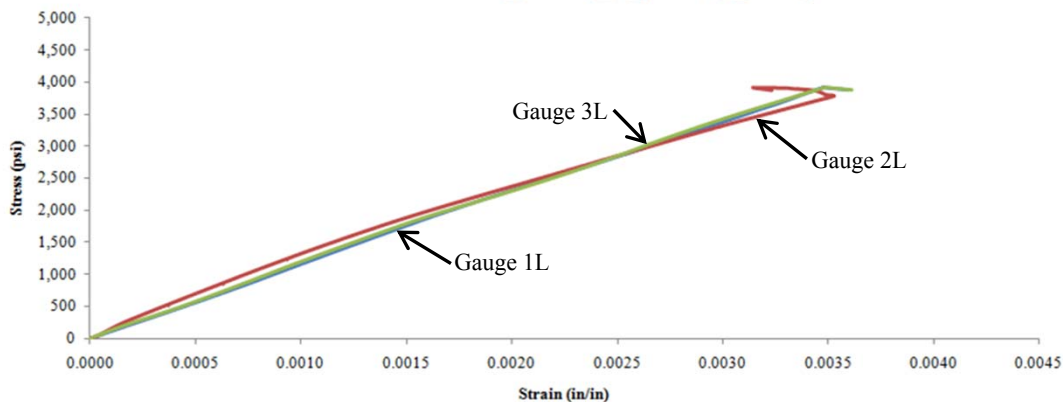
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001668 | 0.000687 | 1,197,181 |
| 2L | 0.001566 | 0.000561 | 1,169,445 |
| 3L | 0.001651 | 0.000663 | 1,189,855 |
| Average | | | 1,185,494 |

Stress-Strain Curve_140°F_1_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-140-FY08**
 Test Date: 8/26/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,985 psi
 Tensile Modulus, E_z : 1,124,261 psi

Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,993 psi
 20% Max Stress: 797 psi

PICTURE OF SPECIMEN PRE-TEST



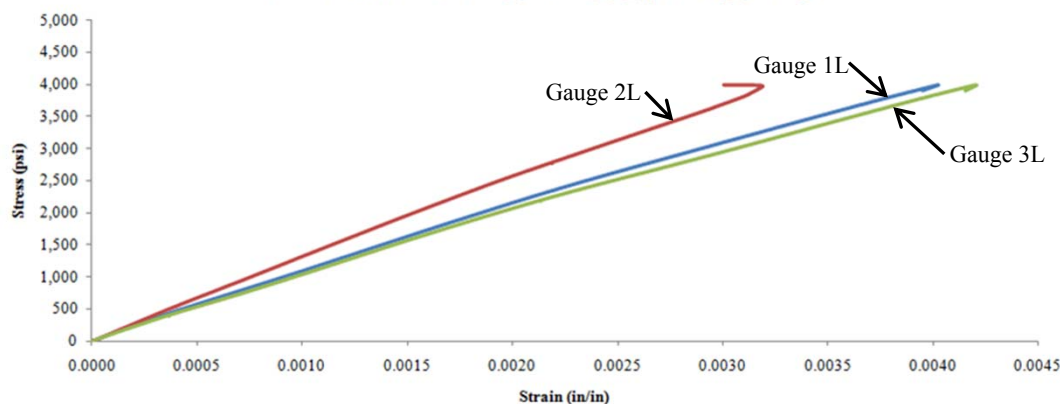
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001842 | 0.000710 | 1,056,095 |
| 2L | 0.001524 | 0.000594 | 1,285,670 |
| 3L | 0.001920 | 0.000760 | 1,031,018 |
| Average | | | 1,124,261 |

Stress-Strain Curve_140°F_2_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-140-FY08**
 Test Date: 8/26/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

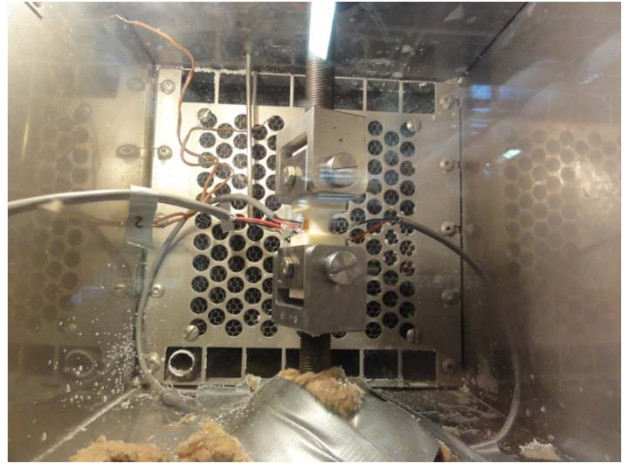
Average Material Properties:

Tensile Strength, ST_z : 3,960 psi
 Tensile Modulus, E_z : 1,018,821 psi

Measured Specimen Dimensions:

Diameter, D: 0.690 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,980 psi
 20% Max Stress: 792 psi

PICTURE OF SPECIMEN PRE-TEST



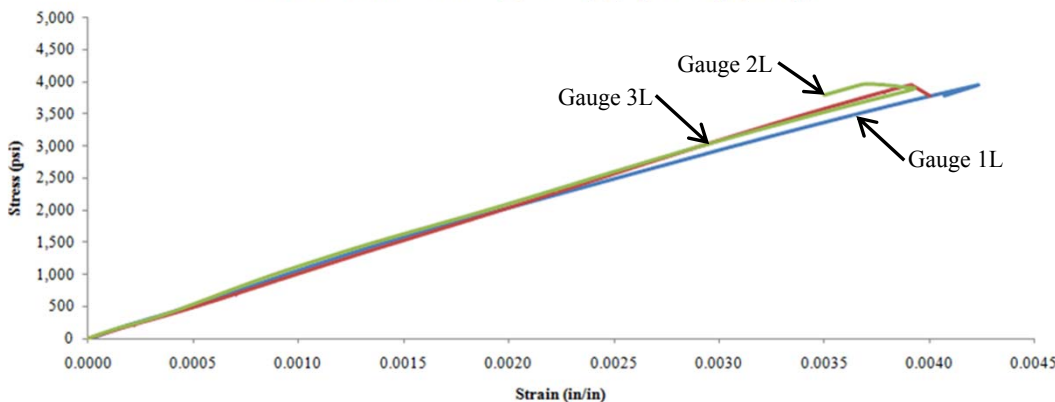
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001925 | 0.000746 | 1,006,907 |
| 2L | 0.001935 | 0.000786 | 1,033,782 |
| 3L | 0.001872 | 0.000702 | 1,015,774 |
| Average | | | 1,018,821 |

Stress-Strain Curve_140°F_3_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-140-FY08**
 Test Date: 8/26/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

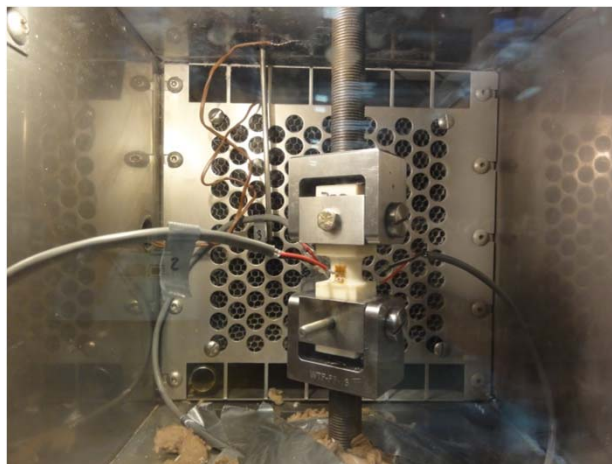
Average Material Properties:

Tensile Strength, ST_z : 3,720 psi
 Tensile Modulus, E_z : 1,075,972 psi

Measured Specimen Dimensions:

Diameter, D: 0.704 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,860 psi
 20% Max Stress: 744 psi

PICTURE OF SPECIMEN PRE-TEST



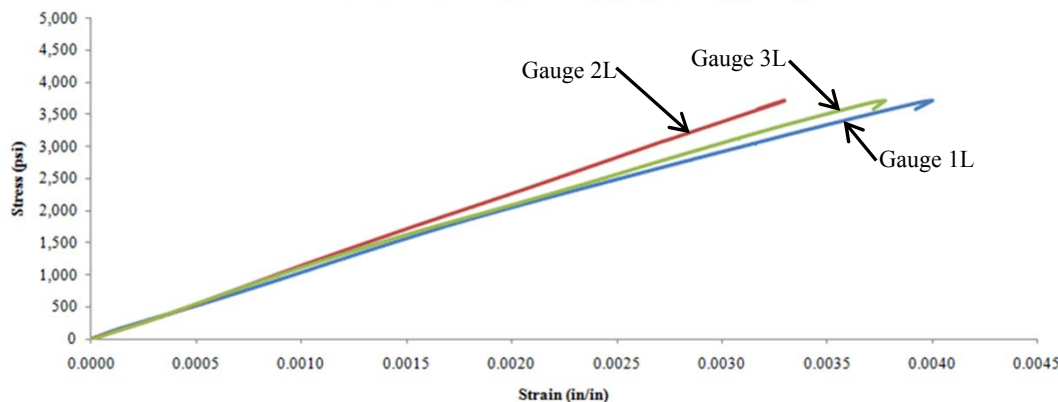
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001788 | 0.000713 | 1,038,567 |
| 2L | 0.001627 | 0.000663 | 1,157,446 |
| 3L | 0.001745 | 0.000664 | 1,031,903 |
| Average | | | 1,075,972 |

Stress-Strain Curve_140°F_4_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-140-FY08**
 Test Date: 8/26/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

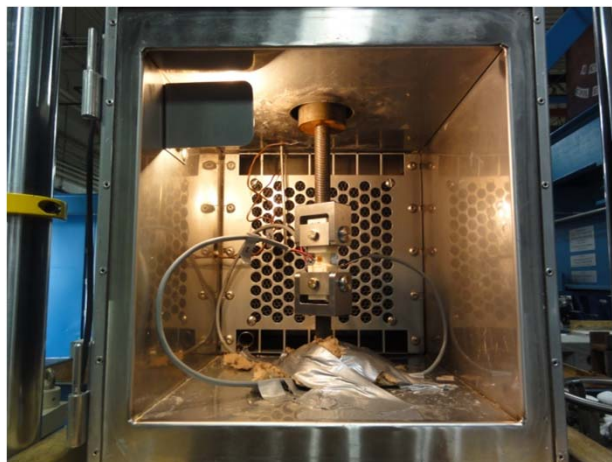
Average Material Properties:

Tensile Strength, ST_z : 3,856 psi
 Tensile Modulus, E_z : 1,128,738 psi

Measured Specimen Dimensions:

Diameter, D: 0.688 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,928 psi
 20% Max Stress: 771 psi

PICTURE OF SPECIMEN PRE-TEST



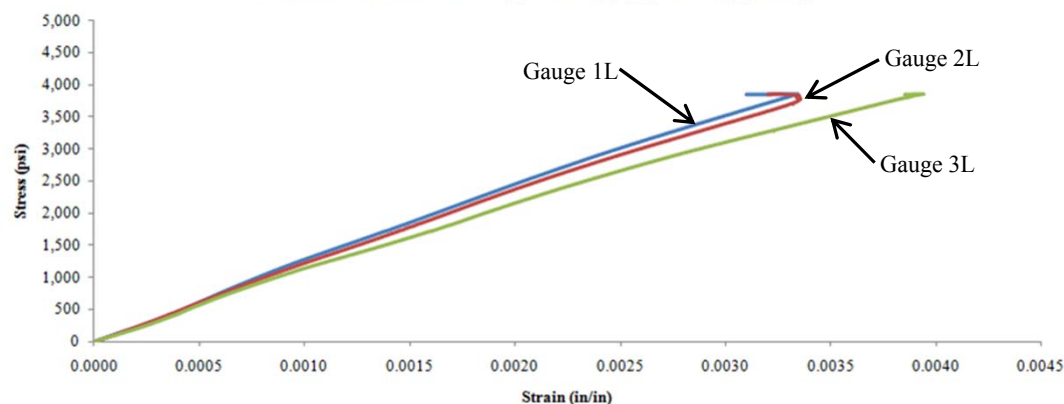
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001560 | 0.000605 | 1,211,034 |
| 2L | 0.001620 | 0.000619 | 1,154,744 |
| 3L | 0.001788 | 0.000654 | 1,020,435 |
| Average | | | 1,128,738 |

Stress-Strain Curve_140°F_5_(08-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CZ-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 57,923 lbs

Compressive Strength, SC_z : 100,317 psi

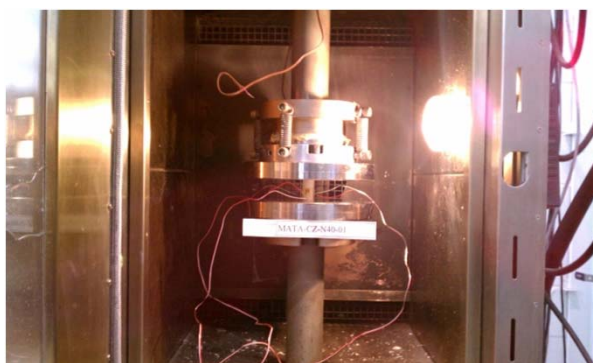
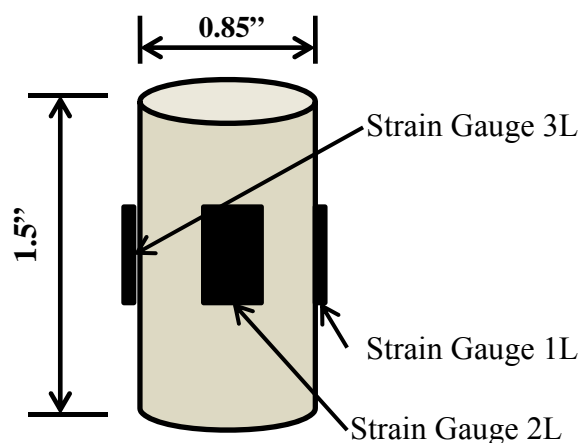
Compressive Modulus, E_z : 1,921,878 psi

Ultimate Strain, ϵ_z : 0.052 in/in

| Specimen | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|------------------------------|---------------------------------|-------------------------------------|--|--------------|
| MAT1-CZ-01-N40-FY08 | 53,333 | 93,567 | 1,888,643 | 0.050 | Rupture |
| MAT1-CZ-02-N40-FY08 | 58,729 | 99,038 | 1,847,760 | 0.054 | Rupture |
| MAT1-CZ-03-N40-FY08 | 57,134 | 99,711 | 1,874,237 | 0.053 | Rupture |
| MAT1-CZ-04-N40-FY08 | 60,418 | 105,997 | 2,032,637 | 0.052 | Rupture |
| MAT1-CZ-05-N40-FY08 | 60,000 | 103,270 | 1,966,112 | 0.053 | Rupture |
| Average | 57,923 | 100,317 | 1,921,878 | 0.052 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference B-74 to B-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-N40-FY08**
 Test Date: 6/10/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 53,333 lbs
 Maximum Stress, SC_z : 93,567 psi
 Elastic Modulus, E_z : 1,888,643 psi
 Ultimate Strain, ϵ_z : 0.050 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 10,667 psi
 50% Max Load: 26,667 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0245 | -0.0093 | 1,847,395 |
| 2L | -0.0223 | -0.0087 | 2,064,964 |
| 3L | -0.0279 | -0.0119 | 1,753,571 |
| Average | | | 1,888,643 |

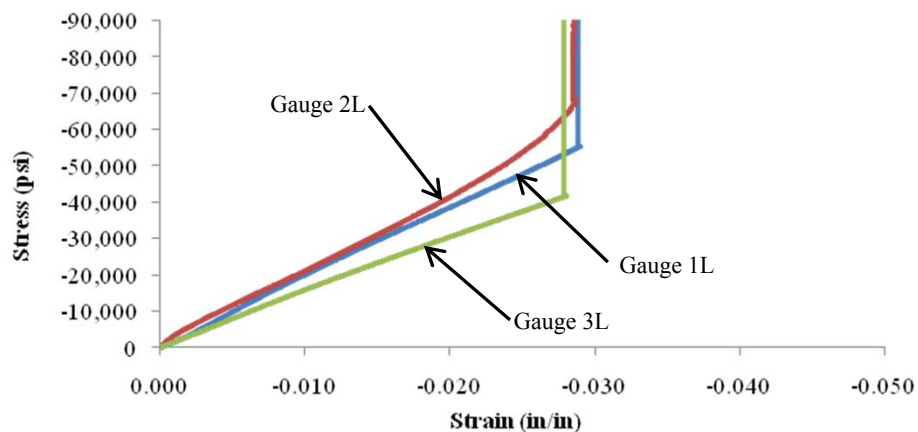
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-N40-FY08**
 Test Date: 6/8/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 58,729 lbs
 Maximum Stress, SC_z : 99,038 psi
 Elastic Modulus, E_z : 1,847,760 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.41 in
 Diameter, D: 0.87 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,746 psi
 50% Max Load: 29,365 psi

PICTURE OF SPECIMEN PRE-TEST



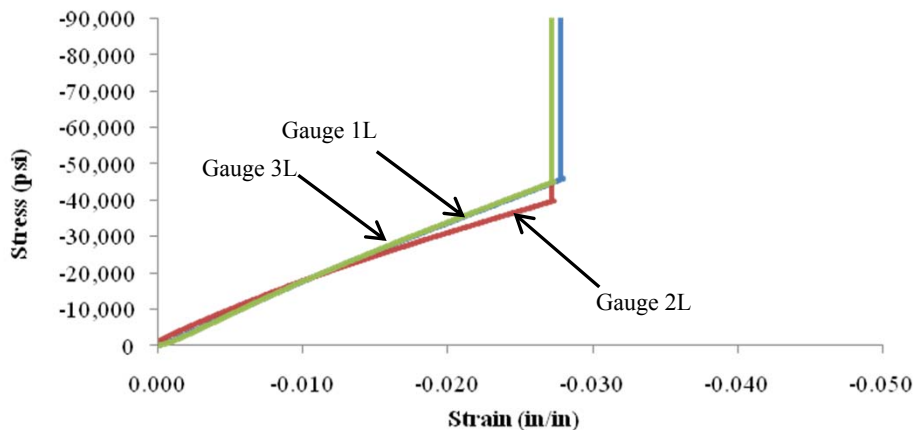
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0278 | -0.0113 | 1,797,120 |
| 2L | -0.0272 | -0.0114 | 1,882,785 |
| 3L | -0.0272 | -0.0112 | 1,863,375 |
| Average | | | 1,847,760 |

Stress-Strain Curve N40_02_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-N40-FY08**
 Test Date: 6/8/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 57,134 lbs
 Maximum Stress, SC_z : 99,711 psi
 Elastic Modulus, E_z : 1,874,237 psi
 Ultimate Strain, ϵ_z : 0.053 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,427 psi
 50% Max Load: 28,567 psi

PICTURE OF SPECIMEN PRE-TEST



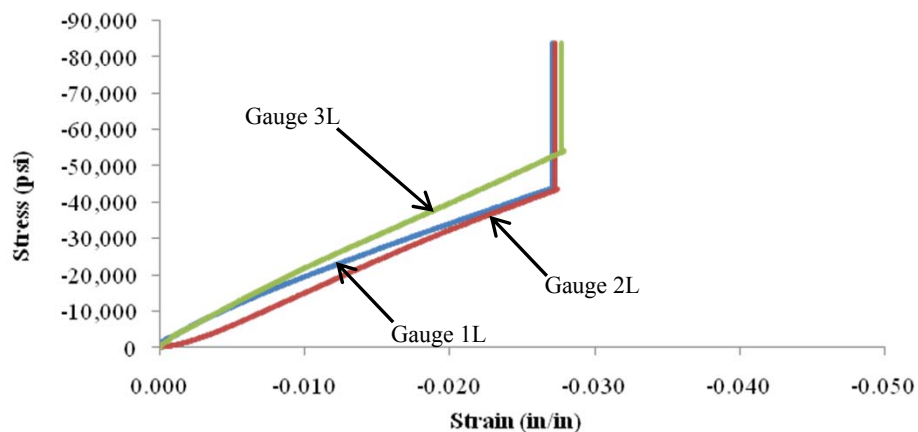
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0271 | -0.0103 | 1,775,747 |
| 2L | -0.0273 | -0.0127 | 2,049,675 |
| 3L | -0.0256 | -0.0090 | 1,797,289 |
| Average | | | 1,874,237 |

Stress-Strain Curve N40_03_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-04-N40-FY08**
 Test Date: 6/8/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 60,418 lbs
 Maximum Stress, SC_z : 105,997 psi
 Elastic Modulus, E_z : 2,032,637 psi
 Ultimate Strain, ϵ_z : 0.052 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.41 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 12,084 psi
 50% Max Load: 30,209 psi

PICTURE OF SPECIMEN PRE-TEST



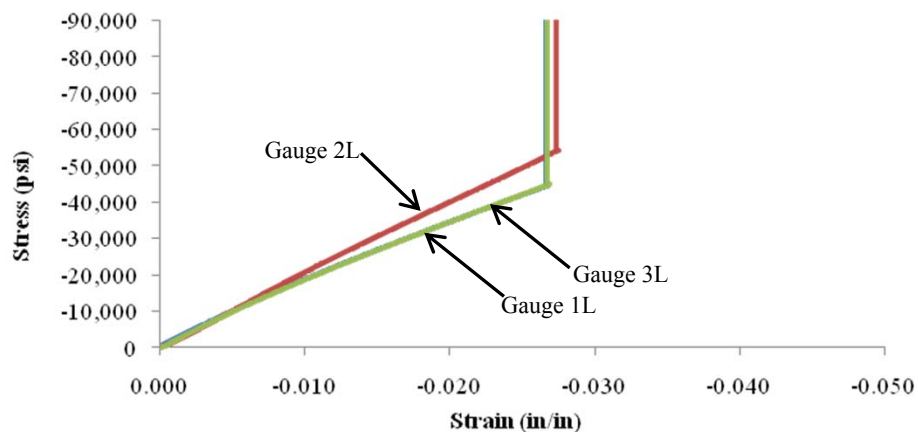
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0267 | -0.0114 | 2,090,341 |
| 2L | -0.0268 | -0.0102 | 1,918,211 |
| 3L | -0.0267 | -0.0115 | 2,089,360 |
| Average | | | 2,032,341 |

Stress-Strain Curve N40_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-N40-FY08**
 Test Date: 6/9/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 60,000 lbs
 Maximum Stress, SC_z : 103,270 psi
 Elastic Modulus, E_z : 1,966,112 psi
 Ultimate Strain, ϵ_z : 0.053 in/in

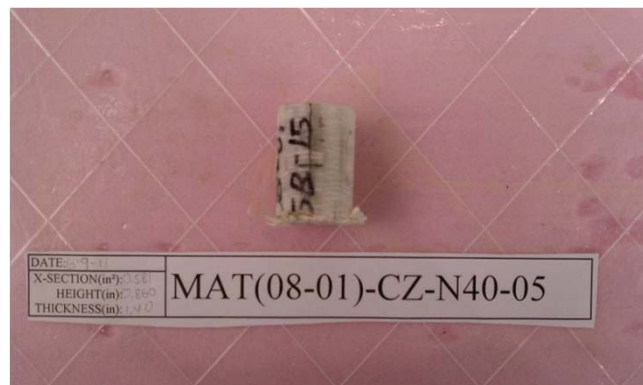
Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.86 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 12,000 psi
 50% Max Load: 30,000 psi

PICTURE OF SPECIMEN PRE-TEST



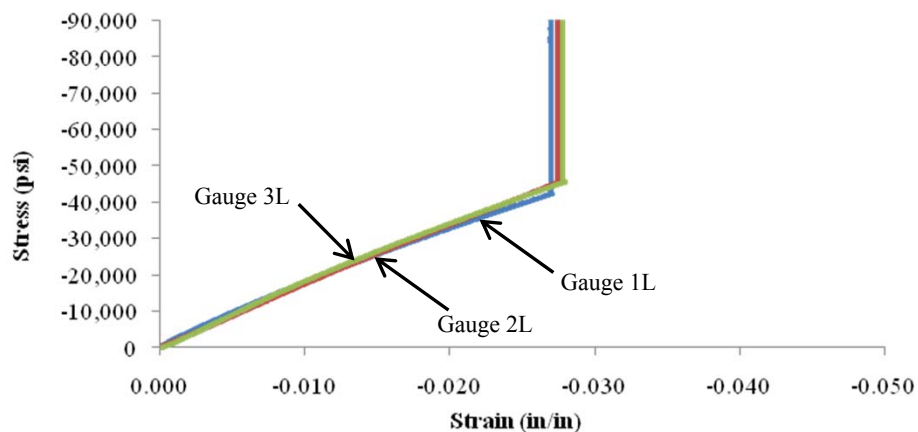
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0270 | -0.0117 | 2,026,815 |
| 2L | -0.0275 | -0.0118 | 1,981,873 |
| 3L | -0.0278 | -0.0114 | 1,889,647 |
| Average | | | 1,966,112 |

Stress-Strain Curve N40_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CZ-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 46,280 lbs

Compressive Strength, SC_z : 80,317 psi

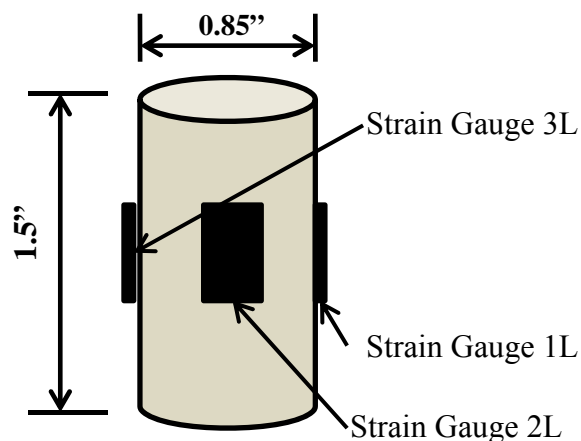
Compressive Modulus, E_z : 1,422,605 psi

Ultimate Strain, ϵ_z : 0.057 in/in

| Specimen | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT1-CZ-01-70-FY08 | 44,356 | 77,682 | 1,562,405 | 0.050 | Rupture |
| MAT1-CZ-02-70-FY08 | 47,250 | 82,460 | 1,468,454 | 0.056 | Rupture |
| MAT1-CZ-03-70-FY08 | 48,520 | 87,110 | 1,407,960 | 0.062 | Rupture |
| MAT1-CZ-04-70-FY08 | 44,538 | 74,980 | 1,397,078 | 0.054 | Rupture |
| MAT1-CZ-05-70-FY08 | 46,738 | 79,352 | 1,277,128 | 0.063 | Rupture |
| Average | 46,280 | 80,317 | 1,422,605 | 0.057 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions
Strain Gauge Configuration****Notes:**

- 1) Reference B-80 to B-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-70-FY08**
 Test Date: 6/2/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 44,356 lbs
 Maximum Stress, SC_z : 77,682 psi
 Elastic Modulus, E_z : 1,562,405 psi
 Ultimate Strain, ϵ_z : 0.050 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.41 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,871 psi
 50% Max Load: 22,178 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0247 | -0.0093 | 1,516,787 |
| 2L | -0.0235 | -0.0086 | 1,565,133 |
| 3L | -0.0225 | -0.0080 | 1,605,294 |
| Average | | | 1,562,405 |

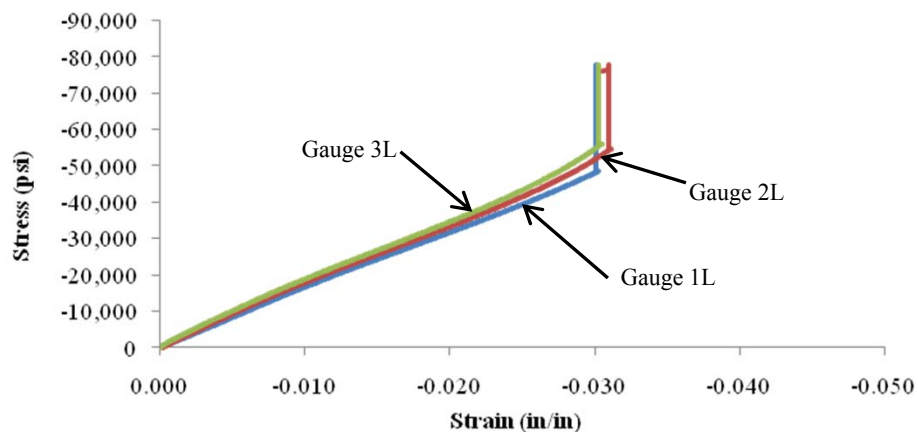
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-70-FY08**
 Test Date: 6/2/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 47,250 lbs
 Maximum Stress, SC_z : 82,460 psi
 Elastic Modulus, E_z : 1,468,454 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.39 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,450 psi
 50% Max Load: 23,625 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0286 | -0.0114 | 1,432,524 |
| 2L | -0.0263 | -0.0083 | 1,370,555 |
| 3L | -0.0258 | -0.0103 | 1,602,285 |
| Average | | | 1,468,454 |

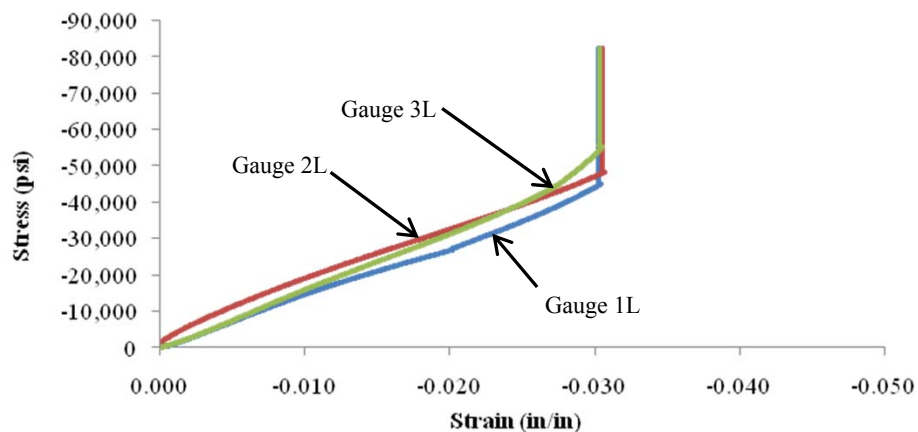
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_02_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-70-FY08**
 Test Date: 6/2/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 48,520 lbs
 Maximum Stress, SC_z : 87,110 psi
 Elastic Modulus, E_z : 1,407,960 psi
 Ultimate Strain, ϵ_z : 0.062 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,704 psi
 50% Max Load: 24,260 psi

PICTURE OF SPECIMEN PRE-TEST



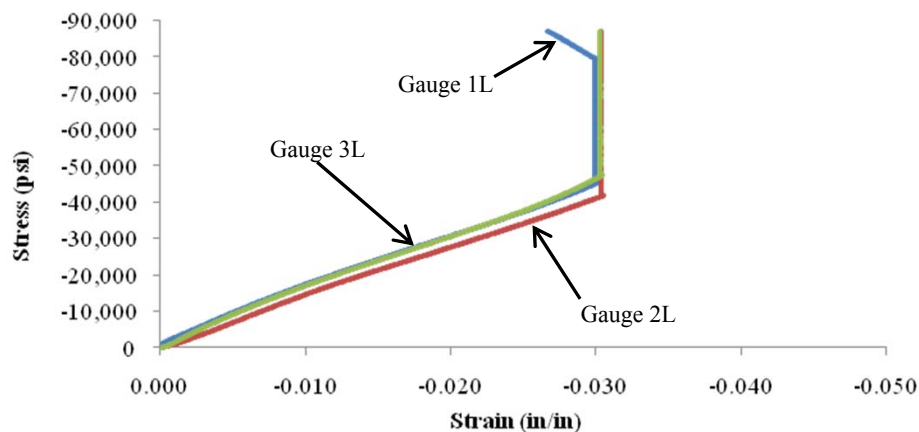
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0291 | -0.0100 | 1,371,923 |
| 2L | -0.0304 | -0.0120 | 1,420,835 |
| 3L | -0.0286 | -0.0103 | 1,431,123 |
| Average | | | 1,407,960 |

Stress-Strain Curve 70F_03_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-04-70-FY08**
 Test Date: 6/2/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 44,538 lbs
 Maximum Stress, SC_z : 74,980 psi
 Elastic Modulus, E_z : 1,397,078 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.87 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,908 psi
 50% Max Load: 22,269 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0238 | -0.0081 | 1,432,560 |
| 2L | -0.0231 | -0.0083 | 1,526,721 |
| 3L | -0.0297 | -0.0115 | 1,231,954 |
| Average | | | 1,397,078 |

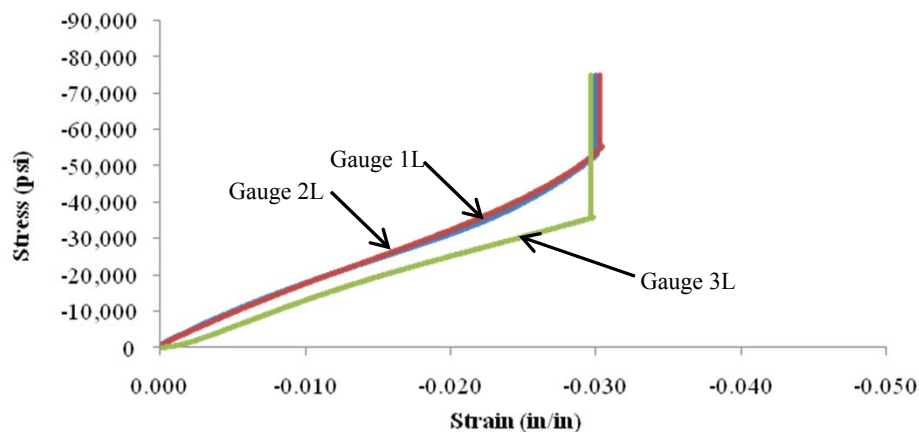
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-70-FY08**
 Test Date: 6/2/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 46,738 lbs
 Maximum Stress, SC_z : 79,352 psi
 Elastic Modulus, E_z : 1,277,128 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.41 in
 Diameter, D: 0.87 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,348 psi
 50% Max Load: 23,369 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0297 | -0.0077 | 1,086,295 |
| 2L | -0.0298 | -0.0127 | 1,391,770 |
| 3L | -0.0297 | -0.0121 | 1,353,318 |
| Average | | | 1,277,128 |

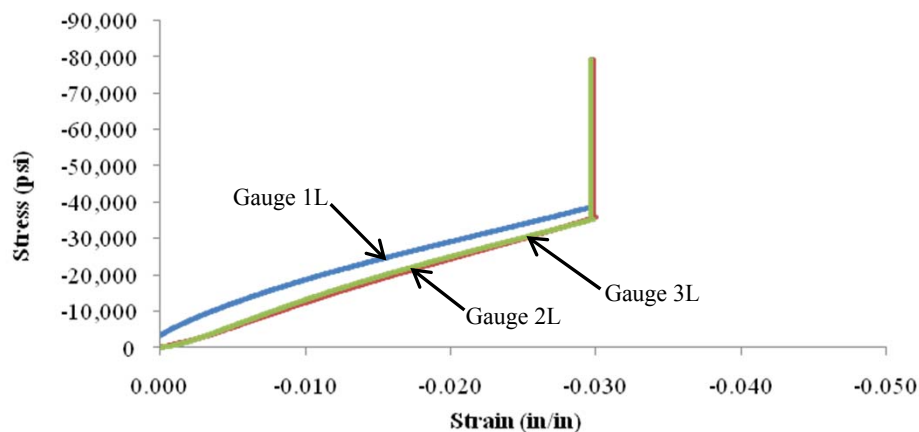
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CZ-140-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 38,221 lbs

Compressive Strength, SC_z : 65,994 psi

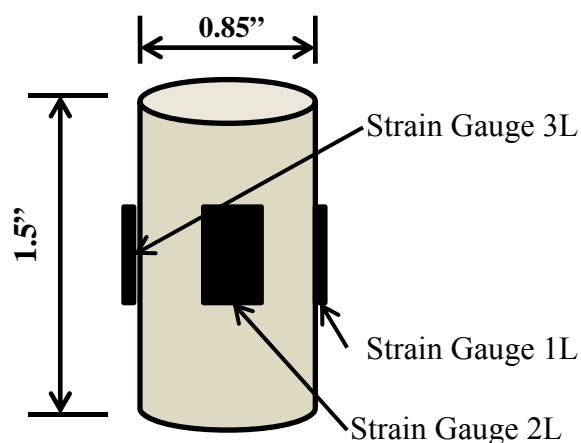
Compressive Modulus, E_z : 1,233,110 psi

Ultimate Strain, ϵ_z : 0.054 in/in

| Specimen | Maximum Load, P_z (lbs) | Maximum Stress, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|------------------------------|---------------------------------|-------------------------------------|--|--------------|
| MAT1-CZ-01-140-FY08 | 38,971 | 65,719 | 1,199,512 | 0.055 | Rupture |
| MAT1-CZ-02-140-FY08 | 38,795 | 67,470 | 1,265,577 | 0.054 | Rupture |
| MAT1-CZ-03-140-FY08 | 36,331 | 64,189 | 1,194,074 | 0.054 | Rupture |
| MAT1-CZ-04-140-FY08 | 40,237 | 67,967 | 1,313,622 | 0.052 | Rupture |
| MAT1-CZ-05-140-FY08 | 36,771 | 64,624 | 1,192,765 | 0.054 | Rupture |
| Average | 38,221 | 65,994 | 1,233,110 | 0.054 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference B-86 to B-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-140-FY08**
 Test Date: 6/6/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 38,971 lbs
 Maximum Stress, SC_z : 65,719 psi
 Elastic Modulus, E_z : 1,199,512 psi
 Ultimate Strain, ϵ_z : 0.055 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.87 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,794 psi
 50% Max Load: 19,486 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0261 | -0.0095 | 1,183,445 |
| 2L | -0.0234 | -0.0086 | 1,329,451 |
| 3L | -0.0289 | -0.0108 | 1,085,640 |
| Average | | | 1,199,512 |

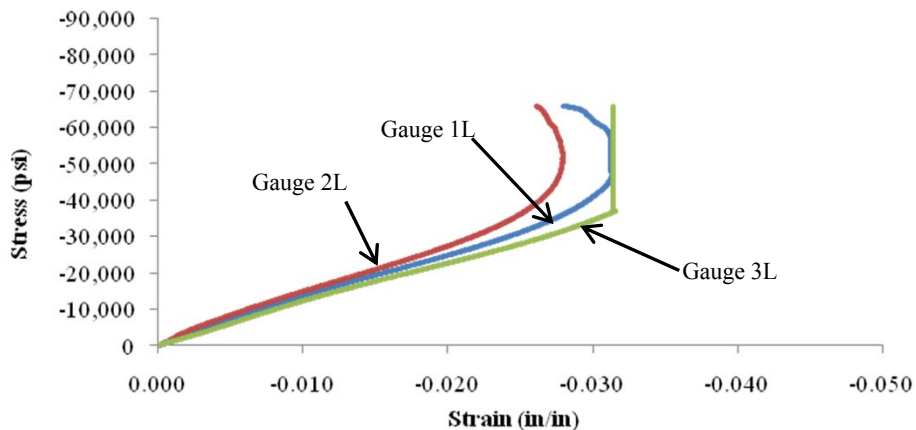
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-140-FY08**
 Test Date: 6/6/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 38,795 lbs
 Maximum Stress, SC_z : 67,470 psi
 Elastic Modulus, E_z : 1,265,577 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.86 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,759 psi
 50% Max Load: 19,398 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0308 | -0.0123 | 1,093,165 |
| 2L | -0.0226 | -0.0070 | 1,297,351 |
| 3L | -0.0260 | -0.0116 | 1,406,215 |
| Average | | | 1,265,577 |

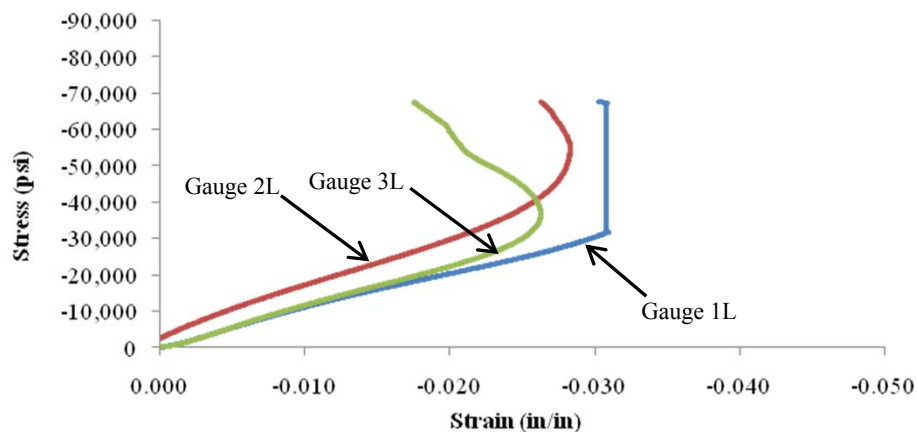
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_02_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-140-FY08**
 Test Date: 6/6/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 36,331 lbs
 Maximum Stress, SC_z : 64,189 psi
 Elastic Modulus, E_z : 1,194,074 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,266 psi
 50% Max Load: 18,166 psi

PICTURE OF SPECIMEN PRE-TEST



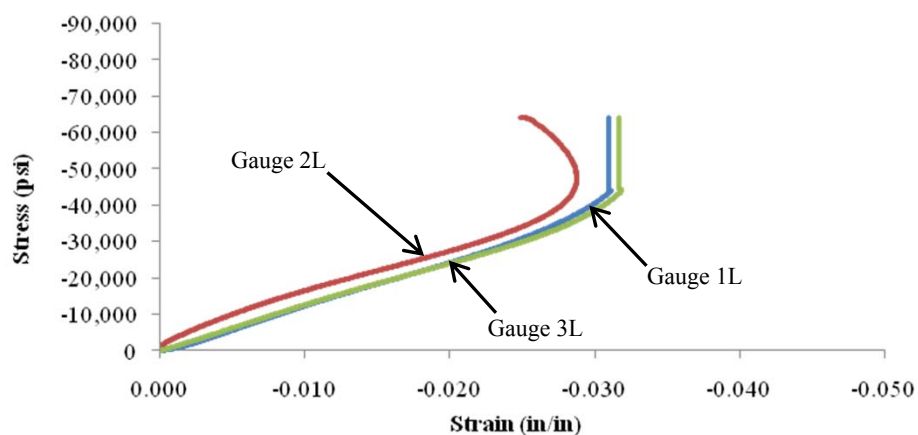
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0256 | -0.0104 | 1,252,771 |
| 2L | -0.0237 | -0.0070 | 1,154,783 |
| 3L | -0.0266 | -0.0102 | 1,174,669 |
| Average | | | 1,194,074 |

Stress-Strain Curve 140F_03_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-04-140-FY08**
 Test Date: 6/6/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 40,237 lbs
 Maximum Stress, SC_z : 67,967 psi
 Elastic Modulus, E_z : 1,313,622 psi
 Ultimate Strain, ϵ_z : 0.052 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.39 in
 Diameter, D: 0.87 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,047 psi
 50% Max Load: 20,118 psi

PICTURE OF SPECIMEN PRE-TEST



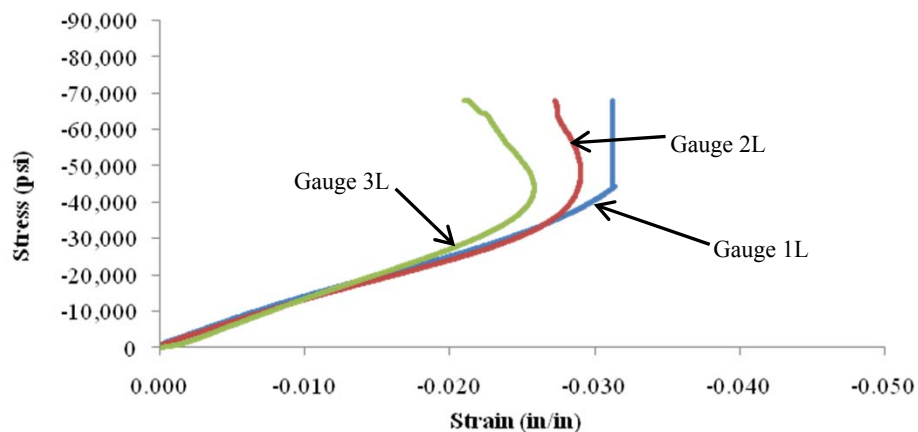
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0266 | -0.0095 | 1,194,463 |
| 2L | -0.0266 | -0.0103 | 1,253,091 |
| 3L | -0.0238 | -0.0101 | 1,493,313 |
| Average | | | 1,313,622 |

Stress-Strain Curve 140F_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-140-FY08**
 Test Date: 6/6/2011
 Specimen Received: 5/27/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 36,771 lbs
 Maximum Stress, SC_z : 64,624 psi
 Elastic Modulus, E_z : 1,192,765 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

Measured/Nominal Specimen Dimensions:

Length, L: 1.40 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,354 psi
 50% Max Load: 18,386 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | Lost Gauge | Lost Gauge | - |
| 2L | -0.0287 | -0.0111 | 1,101,585 |
| 3L | -0.0232 | -0.0081 | 1,283,944 |
| Average | | | 1,192,765 |

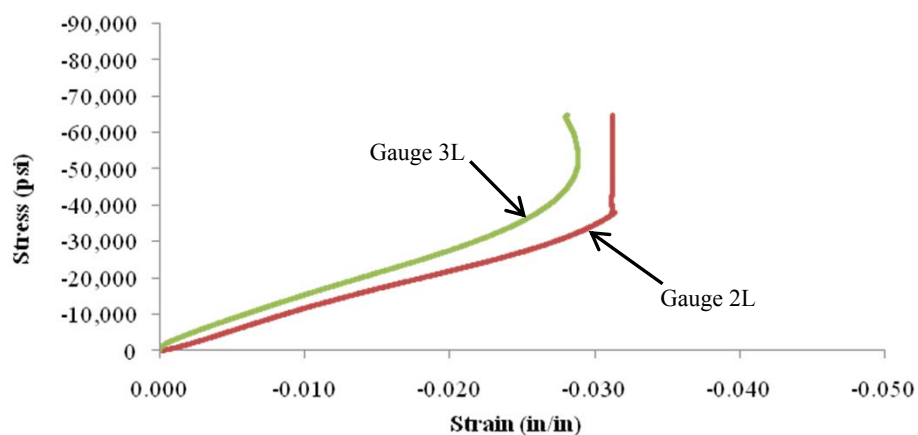
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXZ-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 795 lbs

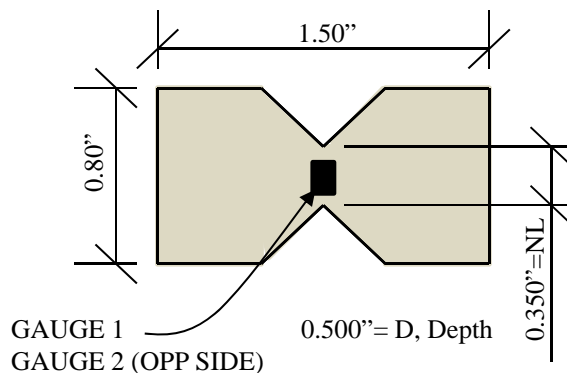
Shear Strength, S_{xz} : 4,571 psi

Shear Modulus, G_{xz} : 837,401 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT1-SXZ-01-N40-FY08 | 798 | 4,615 | 768,557 | Shear |
| MAT1-SXZ-02-N40-FY08 | 772 | 4,477 | 879,433 | Shear |
| MAT1-SXZ-03-N40-FY08 | 806 | 4,624 | 801,651 | Shear |
| MAT1-SXZ-04-N40-FY08 | 813 | 4,576 | 891,049 | Shear |
| MAT1-SXZ-05-N40-FY08 | 787 | 4,563 | 846,314 | Shear |
| Average | 795 | 4,571 | 837,401 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen ,at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

FACING RESEARCHERS

Notes:

- 1) Individual specimen results are shown on Sheets B-92 to B-96
- 2) Six specimens tested, 5 specimens will relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-01-N40-FY08**
 Test Date: 8/29/11
 Specimen Received: 8/16/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **798** lbs
 Shear Strength, S_{xz} : **4,615** psi
 Shear Modulus, G_{xz} : **768,557** psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, N: 0.347 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 399 lbs
 20% Max Load: 160 lbs

PICTURE OF SPECIMEN PRE-TEST



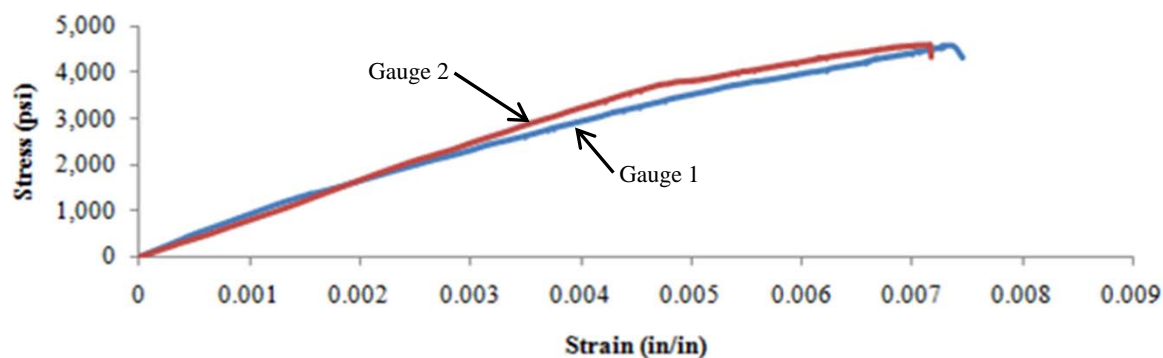
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002972 | 0.000985 | 696,911 |
| 2 | 0.002796 | 0.001148 | 840,203 |
| Average | | | 768,557 |

Stress-Strain Curve N40_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-02-N40-FY08**
 Test Date: 8/29/11
 Specimen Received: 8/16/11
 Properties Measured: S_{xz} , G_{xz}

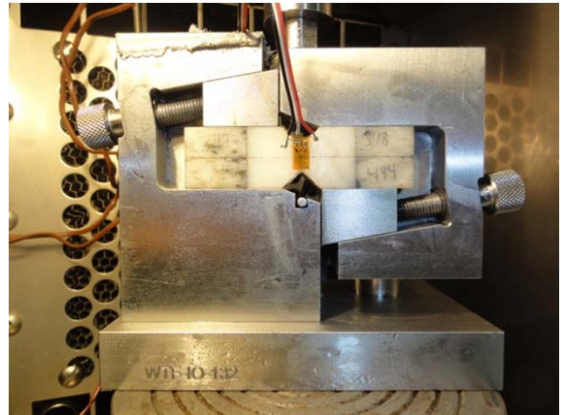
Average Material Properties:

Ultimate Load, P_{max} : **772** lbs
 Shear Strength, S_{xz} : **4,477** psi
 Shear Modulus, G_{xz} : **879,433** psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, N: 0.347 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 386 lbs
 20% Max Load: 154 lbs

PICTURE OF SPECIMEN PRE-TEST



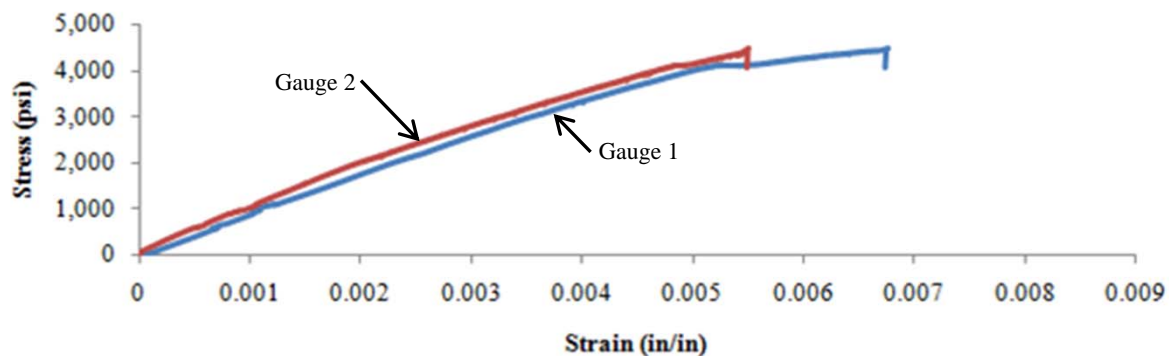
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002602 | 0.001024 | 851,164 |
| 2 | 0.002280 | 0.000801 | 907,701 |
| Average | | | 879,433 |

Stress-Strain Curve N40_02_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-03-N40-FY08**
 Test Date: 8/31/11
 Specimen Received: 8/16/11
 Properties Measured: S_{xz} , G_{xz}

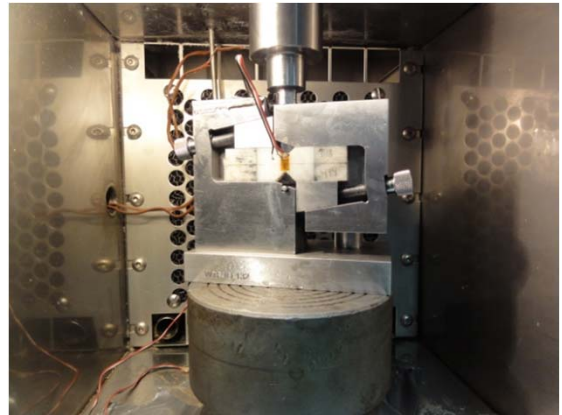
Average Material Properties:

Ultimate Load, P_{max} : **806** **lbs**
Shear Strength, S_{xz} : **4,624** **psi**
Shear Modulus, G_{xz} : **801,651** **psi**

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, N: 0.348 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 403 lbs
 20% Max Load: 161 lbs

PICTURE OF SPECIMEN PRE-TEST



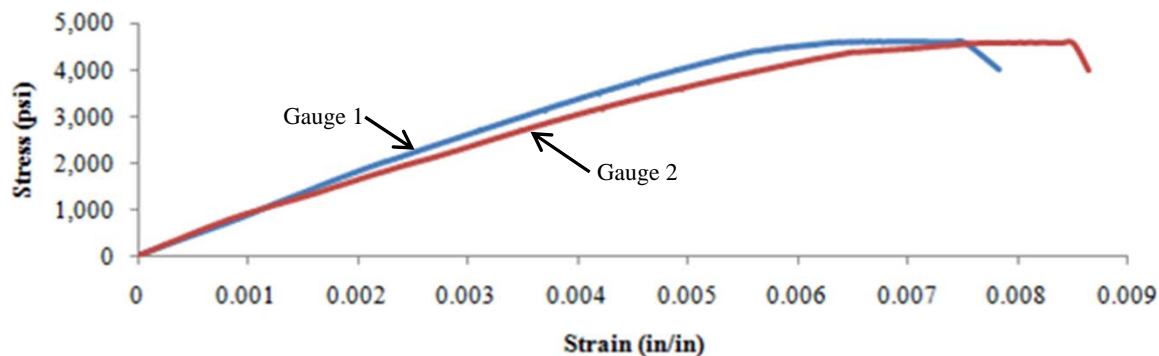
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002615 | 0.001051 | 886,863 |
| 2 | 0.002936 | 0.001000 | 716,439 |
| Average | | | 801,651 |

Stress-Strain Curve N40_03_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-04-N40-FY08**
 Test Date: 8/31/11
 Specimen Received: 8/16/11
 Properties Measured: S_{xz} , G_{xz}

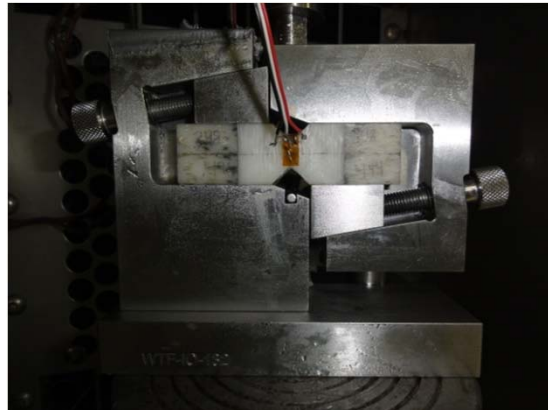
Average Material Properties:

Ultimate Load, P_{max} : **813** **lbs**
Shear Strength, S_{xz} : **4,576** **psi**
Shear Modulus, G_{xz} : **891,049** **psi**

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, N: 0.359 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 407 lbs
 20% Max Load: 163 lbs

PICTURE OF SPECIMEN PRE-TEST



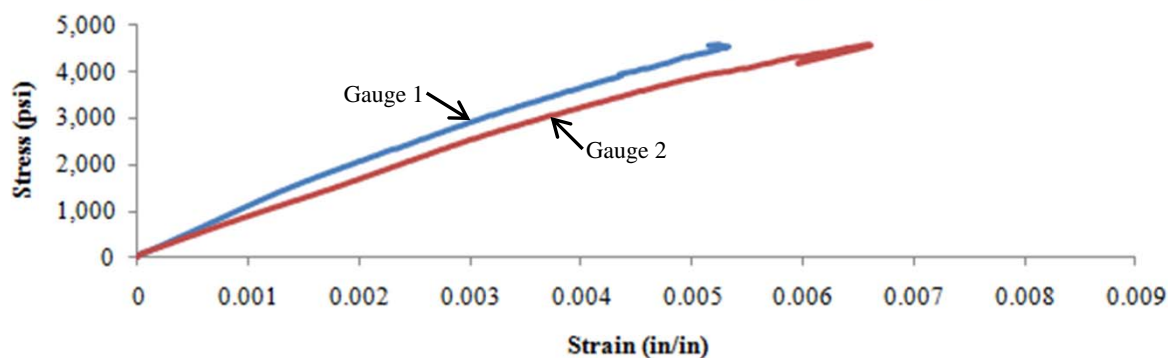
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002258 | 0.000825 | 957,904 |
| 2 | 0.002703 | 0.001038 | 824,195 |
| Average | | | 891,049 |

Stress-Strain Curve N40_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-05-N40-FY08**
 Test Date: 8/31/11
 Specimen Received: 8/16/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **787** **lbs**
Shear Strength, S_{xz} : **4,563** **psi**
Shear Modulus, G_{xz} : **846,314** **psi**

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, N: 0.349 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 393 lbs
 20% Max Load: 157 lbs

PICTURE OF SPECIMEN PRE-TEST



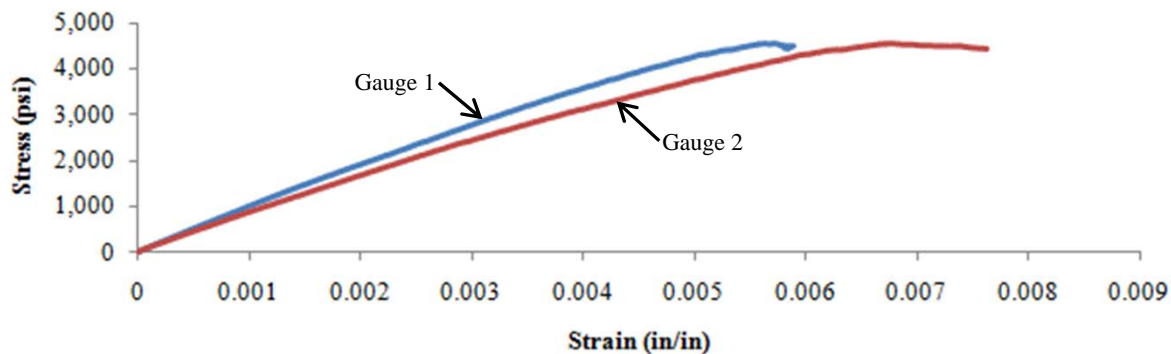
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002419 | 0.000898 | 900,100 |
| 2 | 0.002765 | 0.001038 | 792,528 |
| Average | | | 846,314 |

Stress-Strain Curve N40_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXZ-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 68°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 467 lbs

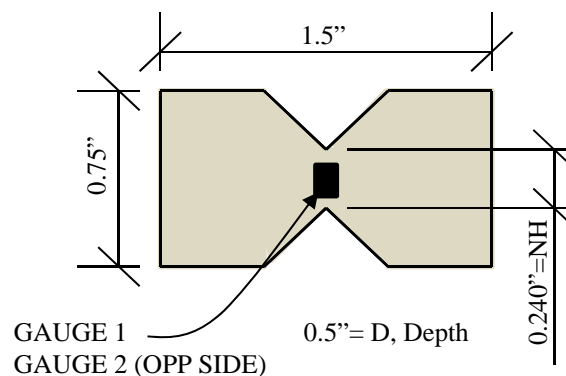
Shear Strength, S_{xz} : 3,804 psi

Shear Modulus, G_{xz} : 864,066 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT1-SXY-01-70-FY08 | 440 | 3,572 | 893,905 | Shear |
| 2 | MAT1-SXY-02-70-FY08 | 541 | 4,477 | 914,688 | Shear |
| 4 | MAT1-SXY-04-70-FY08 | 512 | 4,143 | 907,517 | Shear |
| 5 | MAT1-SXY-05-70-FY08 | 377 | 3,038 | 756,243 | Shear |
| 6 | MAT1-SXY-06-70-FY08 | 464 | 3,790 | 847,977 | Shear |
| Average | | 467 | 3,804 | 864,066 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets B-98 to B-102
- 2) Six specimens tested, with 5 relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-01-70-FY08
 Test Date: 4/26/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 440 lbs
 Shear Stress, S_{xz} : 3,572 psi
 Shear Modulus, G_{xz} : 893,905 psi

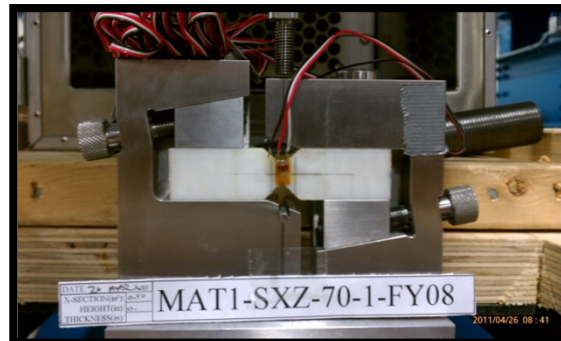
Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NH: 0.246 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 220 lbs
 20% Max Load: 88 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0008 | 961,617 |
| 2 | 0.0020 | 0.0007 | 826,192 |
| Average | | | 893,905 |

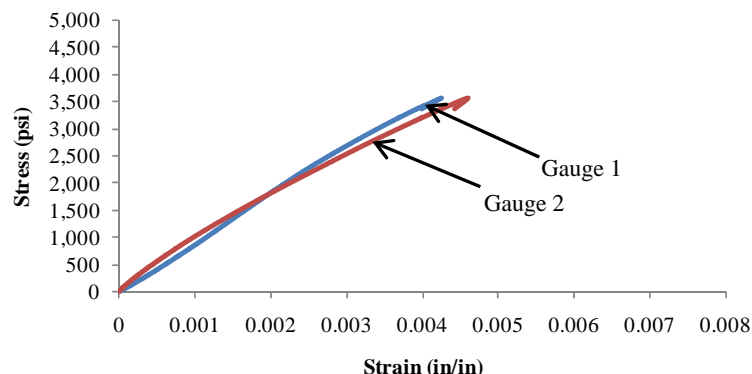
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-02-70-FY08
 Test Date: 4/26/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

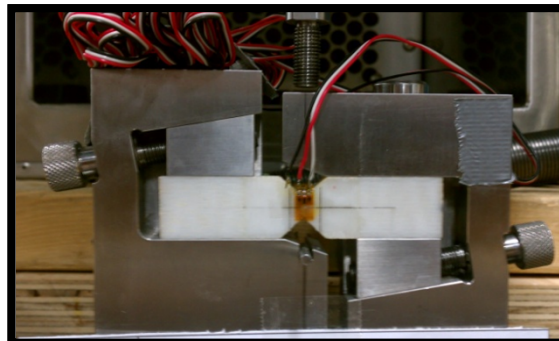
Average Material Properties:

Ultimate Load, P_{max} : 541 lbs
 Shear Stress, S_{xz} : 4,477 psi
 Shear Modulus, G_{xz} : 914,688 psi

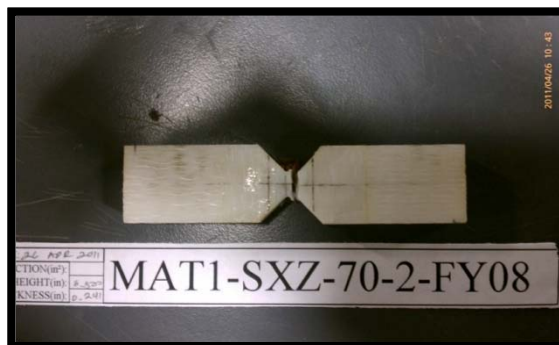
Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NH: 0.241 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 270 lbs
 20% Max Load: 108 lbs

PICTURE OF SPECIMEN PRE-TEST



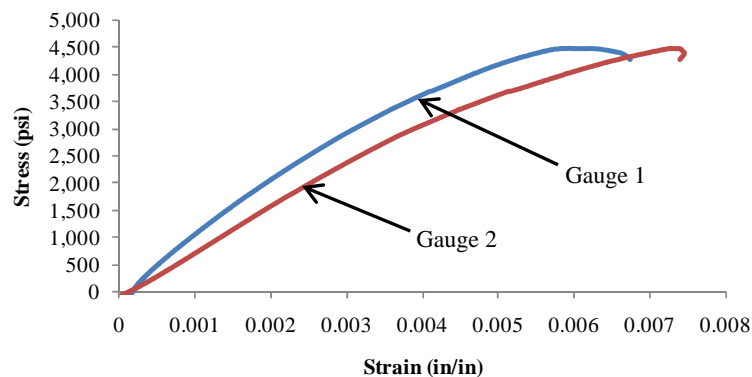
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0022 | 0.0008 | 999,227 |
| 2 | 0.0028 | 0.0012 | 830,149 |
| Average | | | 914,688 |

Stress-Strain Curve 70F_02_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-04-70-FY08
 Test Date: 4/26/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

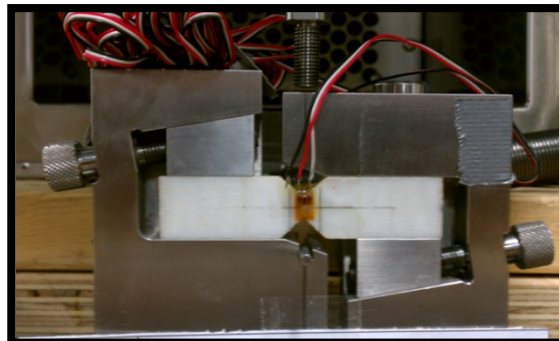
Average Material Properties:

Ultimate Load, P_{max} : 512 lbs
 Shear Stress, S_{xz} : 4,143 psi
 Shear Modulus, G_{xz} : 907,517 psi

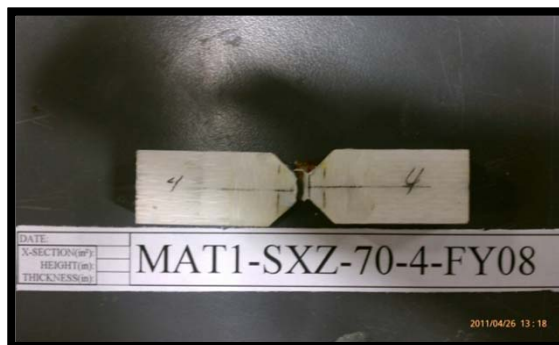
Measured Specimen Dimensions:

Depth, D: 0.504 in
 Notch Length, NH: 0.245 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 256 lbs
 20% Max Load: 102 lbs

PICTURE OF SPECIMEN PRE-TEST



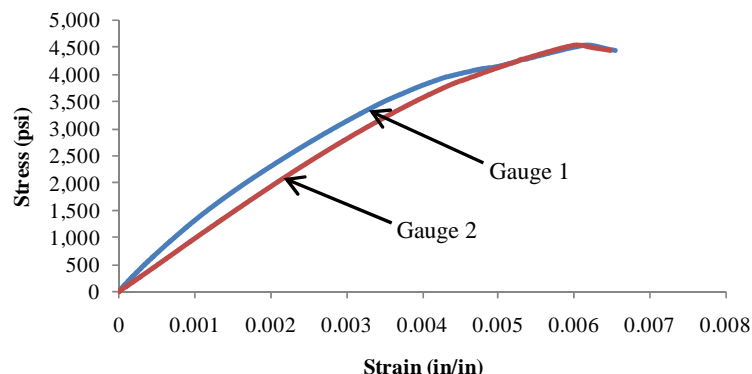
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0007 | 954,672 |
| 2 | 0.0024 | 0.0009 | 860,361 |
| Average | | | 907,517 |

Stress-Strain Curve 70F_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-05-70-FY08
 Test Date: 4/26/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

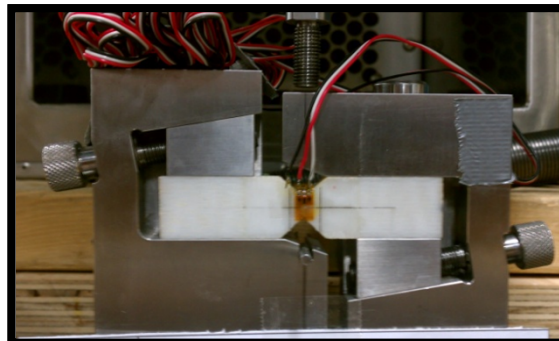
Average Material Properties:

Ultimate Load, P_{max} : 377 lbs
 Shear Stress, S_{xz} : 3,038 psi
 Shear Modulus, G_{xz} : 756,243 psi

Measured Specimen Dimensions:

Depth, D: 0.505 in
 Notch Length, NH: 0.246 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 189 lbs
 20% Max Load: 75 lbs

PICTURE OF SPECIMEN PRE-TEST



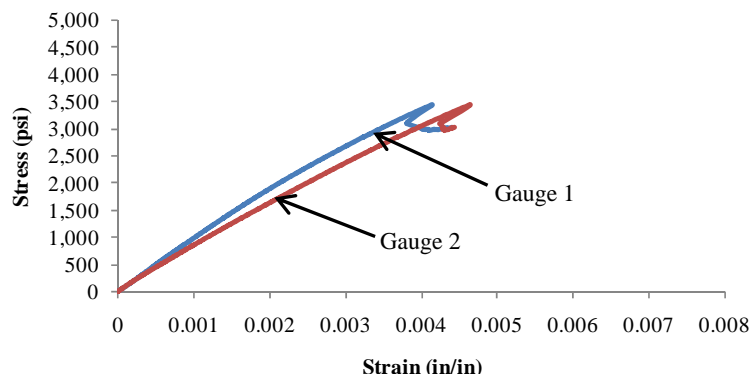
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0018 | 0.0007 | 823,849 |
| 2 | 0.0021 | 0.0008 | 688,636 |
| Average | | | 756,243 |

Stress-Strain Curve 70F_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-06-70-FY08
 Test Date: 4/26/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

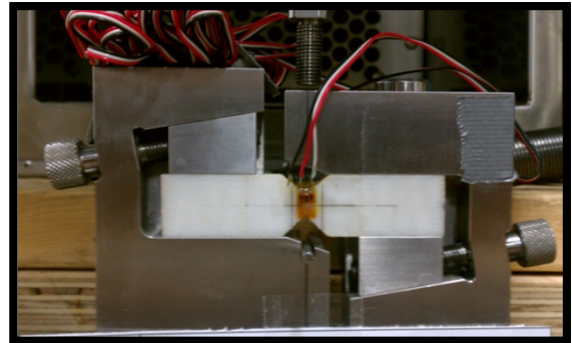
Average Material Properties:

Ultimate Load, P_{max} : 464 lbs
 Shear Stress, S_{xz} : 3,790 psi
 Shear Modulus, G_{xz} : 847,977 psi

Measured Specimen Dimensions:

Depth, D: 0.506 in
 Notch Length, NH: 0.242 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 232 lbs
 20% Max Load: 93 lbs

PICTURE OF SPECIMEN PRE-TEST



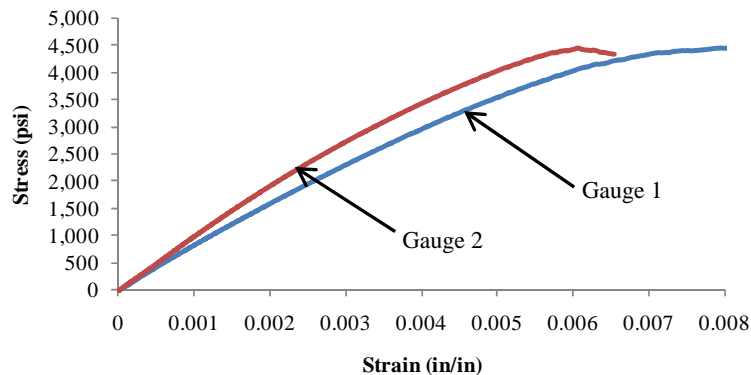
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0008 | 961,617 |
| 2 | 0.0020 | 0.0007 | 826,192 |
| Average | | | 893,905 |

Stress-Strain Curve 70F_06_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXZ-140-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 390 lbs

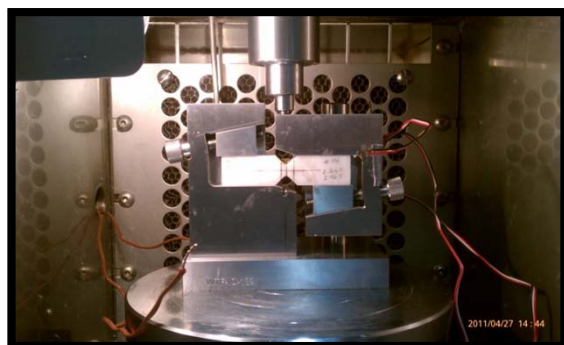
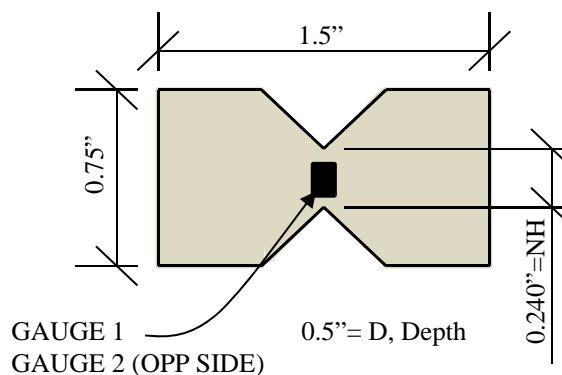
Shear Strength, S_{xz} : 3,087 psi

Shear Modulus, G_{xz} : 700,184 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT1-SXY-01-140-FY08 | 364 | 2,860 | 514,887 | Shear |
| 3 | MAT1-SXY-03-140-FY08 | 361 | 2,881 | 679,389 | Shear |
| 4 | MAT1-SXY-04-140-FY08 | 416 | 3,384 | 831,823 | Shear |
| 5 | MAT1-SXY-05-140-FY08 | 387 | 3,166 | 736,910 | Shear |
| 6 | MAT1-SXY-06-140-FY08 | 419 | 3,146 | 737,910 | Shear |
| Average | | 390 | 3,087 | 700,184 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140° F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets B-104 to B-108
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-01-140-FY08
 Test Date: 4/27/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

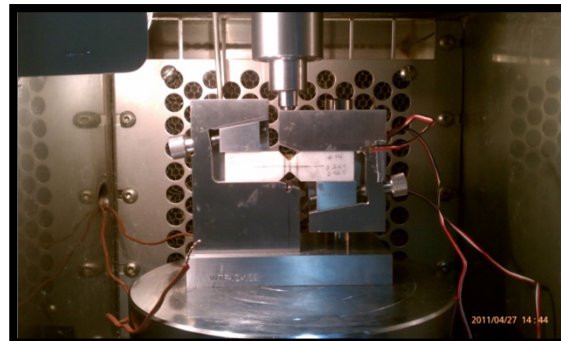
Average Material Properties:

Ultimate Load, P_{max} : 364 lbs
 Shear Stress, S_{xz} : 2,860 psi
 Shear Modulus, G_{xz} : 514,887 psi

Measured Specimen Dimensions:

Depth, D: 0.482 in
 Notch Height, NH: 0.264 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 182 lbs
 20% Max Load: 73 lbs

PICTURE OF SPECIMEN PRE-TEST



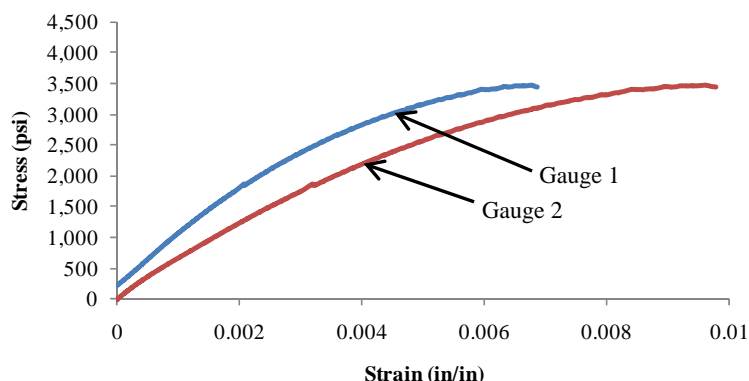
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0006 | 603,549 |
| 2 | 0.0031 | 0.0011 | 426,225 |
| Average | | | 514,887 |

Stress-Strain Curve 140F_01_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-03-140-FY08
 Test Date: 4/27/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

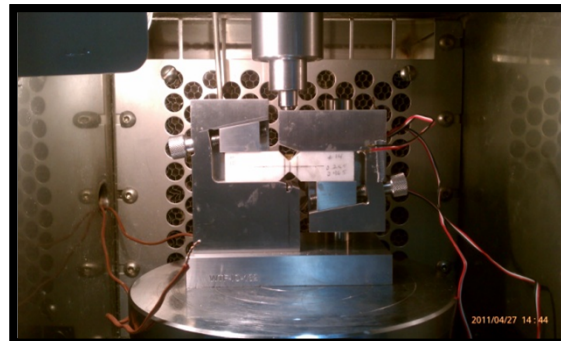
Average Material Properties:

Ultimate Load, P_{max} : 361 lbs
 Shear Stress, S_{xz} : 2,881 psi
 Shear Modulus, G_{xz} : 679,389 psi

Measured Specimen Dimensions:

Depth, D: 0.49 in
 Notch Height, NH: 0.256 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 181 lbs
 20% Max Load: 72 lbs

PICTURE OF SPECIMEN PRE-TEST



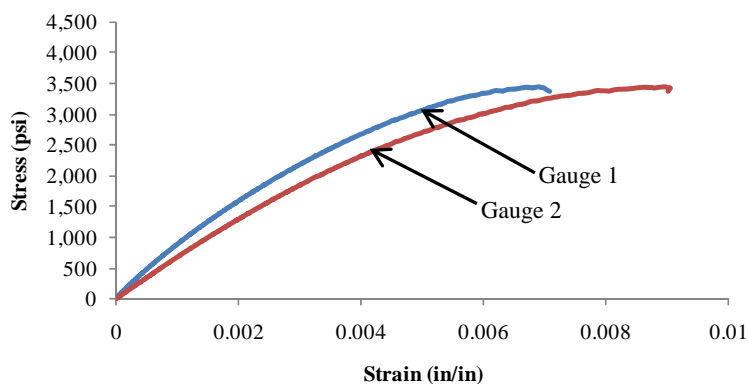
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0018 | 0.0006 | 745,511 |
| 2 | 0.0023 | 0.0008 | 613,266 |
| Average | | | 679,389 |

Stress-Strain Curve 140F_03_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-04-140-FY08
 Test Date: 4/27/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

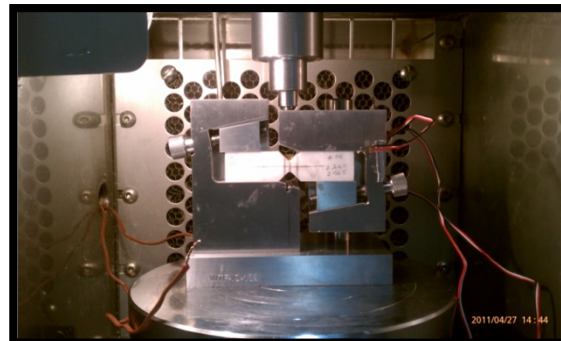
Average Material Properties:

Ultimate Load, P_{max} : 416 lbs
 Shear Stress, S_{xz} : 3,384 psi
 Shear Modulus, G_{xz} : 831,823 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Height, NH: 0.245 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 208 lbs
 20% Max Load: 83 lbs

PICTURE OF SPECIMEN PRE-TEST



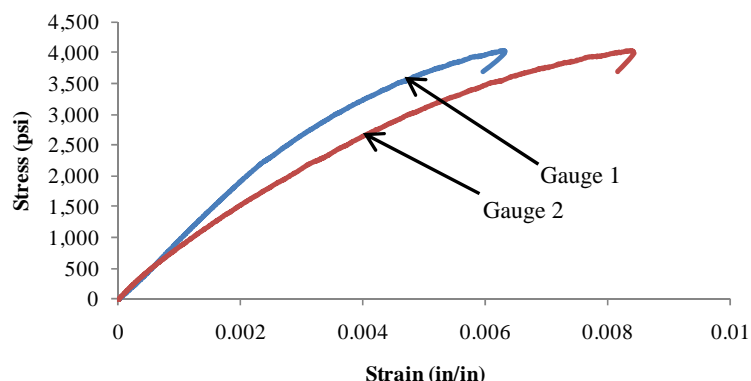
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0017 | 0.0007 | 983,817 |
| 2 | 0.0023 | 0.0008 | 679,830 |
| Average | | | 831,823 |

Stress-Strain Curve 140F_04_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-05-140-FY08
 Test Date: 4/27/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

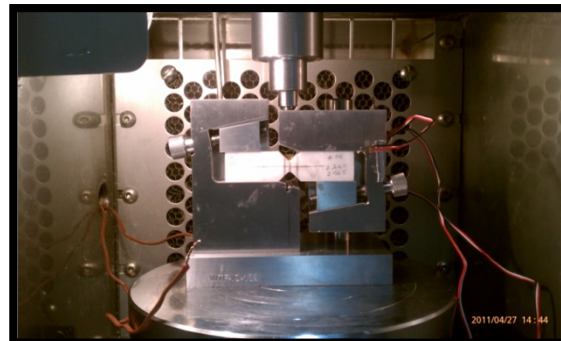
Average Material Properties:

Ultimate Load, P_{max} : 387 lbs
 Shear Stress, S_{xz} : 3,166 psi
 Shear Modulus, G_{xz} : 736,910 psi

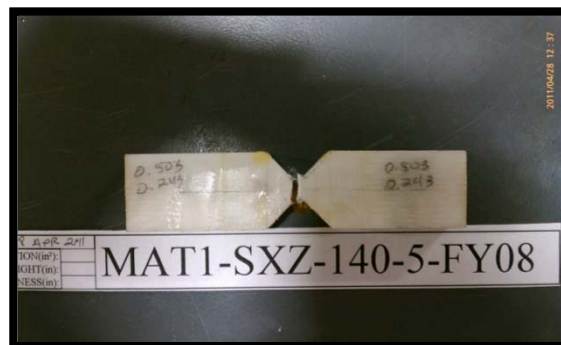
Measured Specimen Dimensions:

Depth, D: 0.503 in
 Notch Height, NH: 0.243 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 194 lbs
 20% Max Load: 77 lbs

PICTURE OF SPECIMEN PRE-TEST



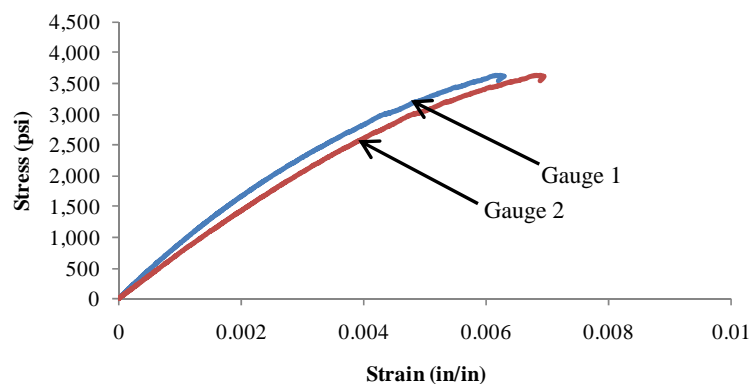
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0019 | 0.0007 | 788,862 |
| 2 | 0.0022 | 0.0008 | 684,957 |
| Average | | | 736,910 |

Stress-Strain Curve 140F_05_(08-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXZ-06-140-FY08
 Test Date: 4/27/11
 Specimen Received: 4/18/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 419 lbs
 Shear Stress, S_{xz} : 3,146 psi
 Shear Modulus, G_{xz} : 737,910 psi

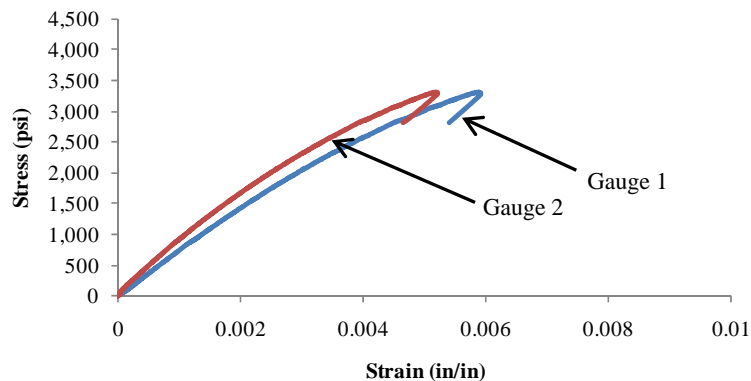
Measured Specimen Dimensions:

Depth, D: 0.507 in
 Notch Height, NH: 0.263 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 210 lbs
 20% Max Load: 84 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0022 | 0.0008 | 687,651 |
| 2 | 0.0018 | 0.0006 | 788,169 |
| Average | | | 737,910 |

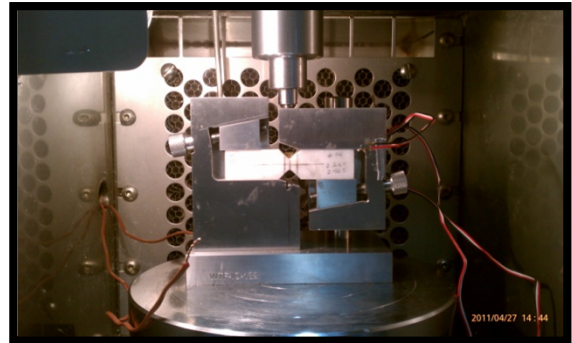
Stress-Strain Curve 140F_06_(08-01)



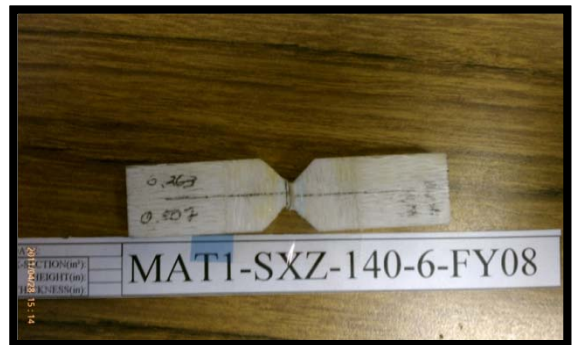
Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-N40-FY08

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured:

Average Material Properties (5 Specimens):

Poisson’s Ratio, ν_{xz} : 0.170

Maximum Load, P_z : 3,523 lbs

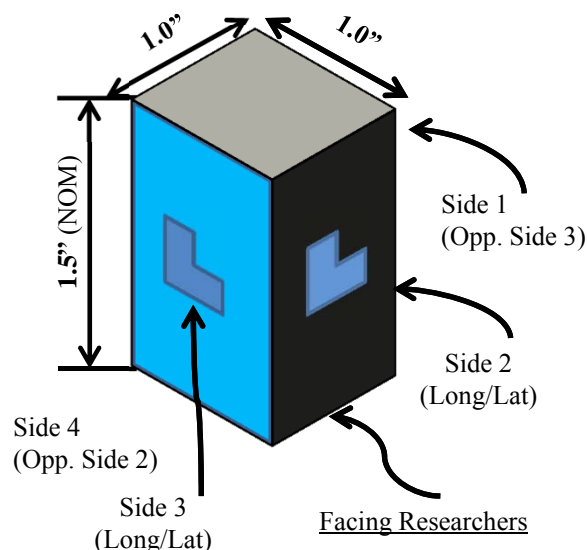
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT1-OP-1-N40-FY08 | 3,518 | 0.2279 | Rupture |
| 2 | MAT1-OP-2-N40-FY08 | 4,661 | 0.1845 | Rupture |
| 3 | MAT1-OP-3-N40-FY08 | 3,508 | 0.1457 | Rupture |
| 4 | MAT1-OP-4-N40-FY08 | 2,708 | 0.1347 | Bondline |
| 5 | MAT1-OP-5-N40-FY08 | 3,221 | 0.1580 | Rupture |
| Average | | 3,523 | 0.170 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) Reference G-32 thru G-36 for individual specimen data.
- 2) 8 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-N40-FY08**
 Test Date: 3/14/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,518 lbs
 Poisson's Ratio, v_{xz} : 0.2279

Measured Specimen Dimensions:

Thickness: 1.50 in
 Side 1: 1.00 in
 Side 2: 1.00 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,759 lbs
 20% Max Load: 704 lbs

PICTURE OF SPECIMEN PRE-TEST

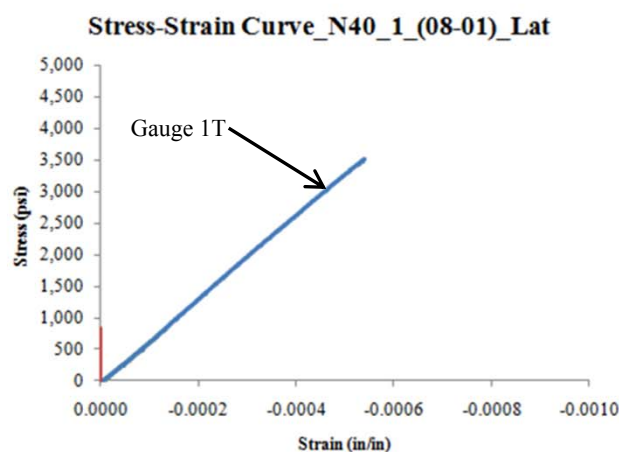
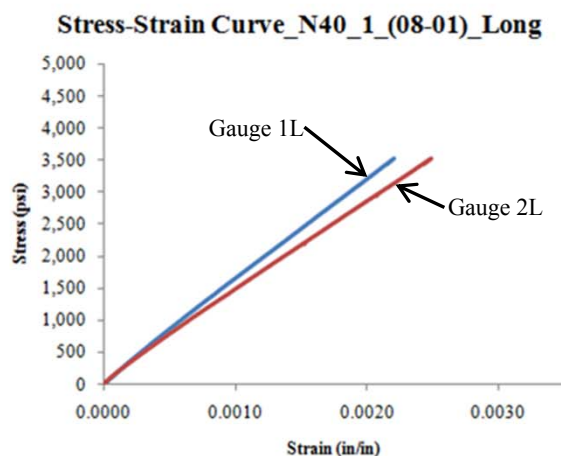


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001062 | 0.000393 | 1T | -0.000268 | -0.000115 | 0.2279 |
| 2L | 0.001193 | 0.000437 | 2T | LOST GAUGE | | - |
| Average | | | | | | 0.2279 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-N40-FY08**
 Test Date: 3/15/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,661 lbs
 Poisson's Ratio, v_{xz} : 0.1845

Measured Specimen Dimensions:

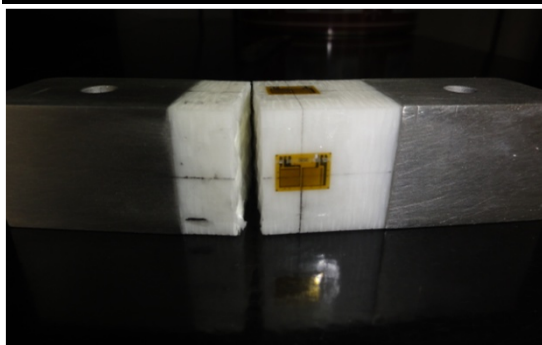
Thickness: 1.50 in
 Side 1: 1.00 in
 Side 2: 1.00 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,330 lbs
 20% Max Load: 932 lbs

PICTURE OF SPECIMEN PRE-TEST

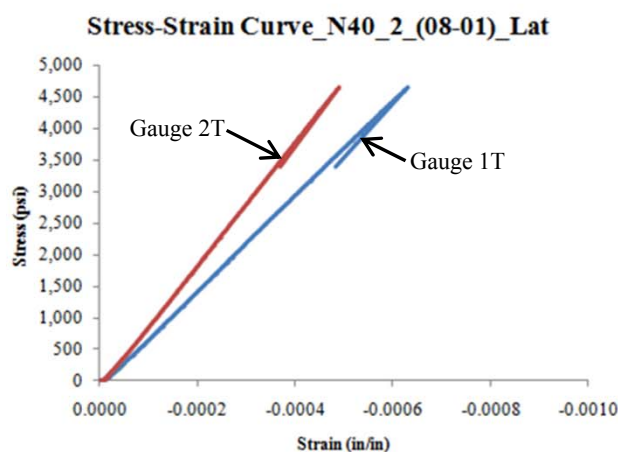
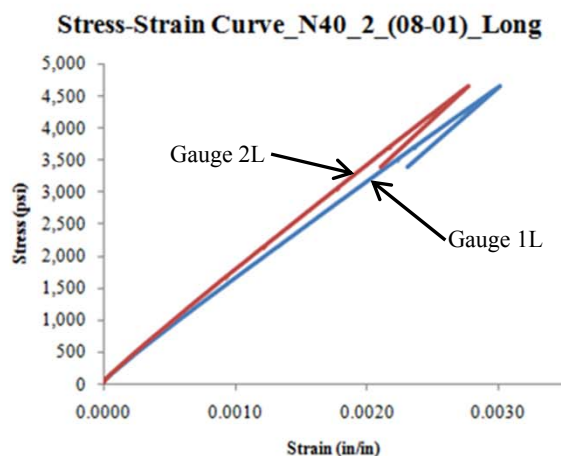


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001444 | 0.000529 | 1T | -0.000320 | -0.000138 | 0.1985 |
| 2L | 0.001324 | 0.000488 | 2T | -0.000252 | -0.000110 | 0.1706 |
| Average | | | | | | 0.1845 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-N40-FY08**
 Test Date: 3/24/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,508 lbs
 Poisson's Ratio, v_{xz} : 0.1457

Measured Specimen Dimensions:

Thickness: 1.50 in
 Side 1: 1.00 in
 Side 2: 1.00 in

Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,754 lbs

20% Max Load: 702 lbs

PICTURE OF SPECIMEN PRE-TEST

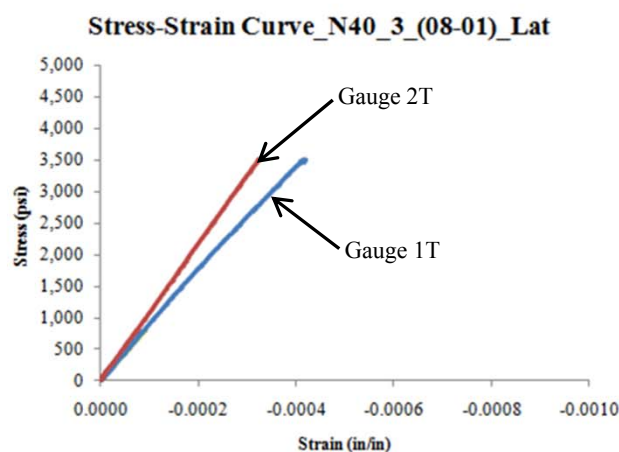
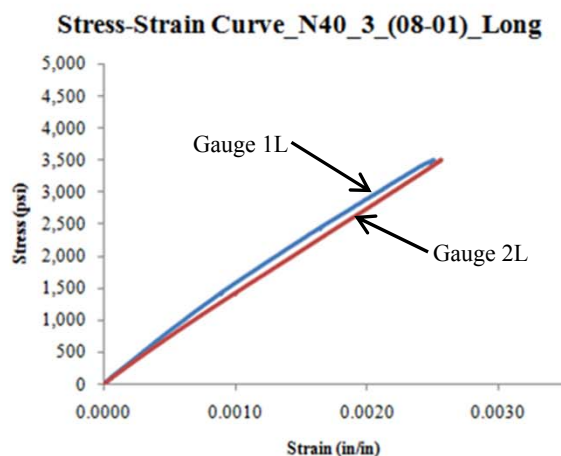


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001126 | 0.000414 | 1T | -0.000197 | -0.000078 | 0.1667 |
| 2L | 0.001245 | 0.000465 | 2T | -0.000163 | -0.000065 | 0.1246 |
| Average | | | | | | 0.1457 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-N40-FY08**
 Test Date: 3/24/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 2,708 lbs
 Poisson's Ratio, v_{xz} : 0.1347

Measured Specimen Dimensions:

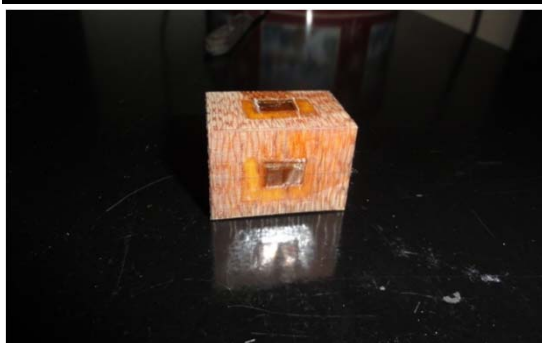
Thickness: 1.50 in
 Side 1: 1.00 in
 Side 2: 1.00 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,354 lbs
 20% Max Load: 542 lbs

PICTURE OF SPECIMEN PRE-TEST

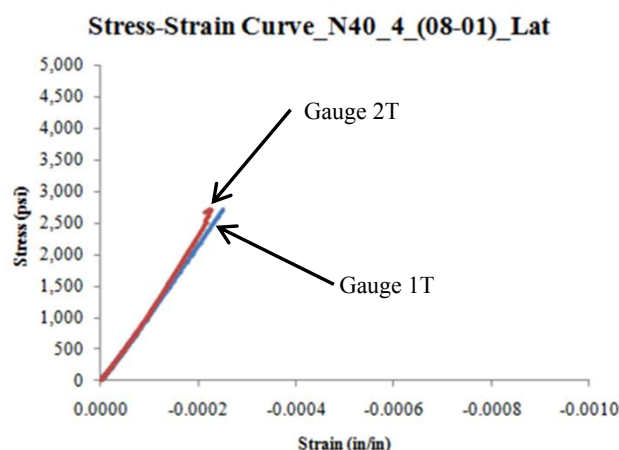
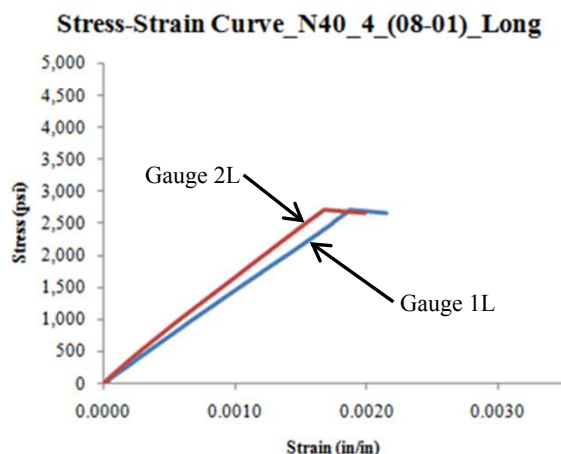


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000932 | 0.000367 | 1T | -0.000129 | -0.000057 | 0.1286 |
| 2L | 0.000805 | 0.000300 | 2T | -0.000125 | -0.000054 | 0.1408 |
| Average | | | | | | 0.1347 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-N40-FY08**
 Test Date: 4/01/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,221 lbs
 Poisson's Ratio, v_{xz} : 0.1580

Measured Specimen Dimensions:

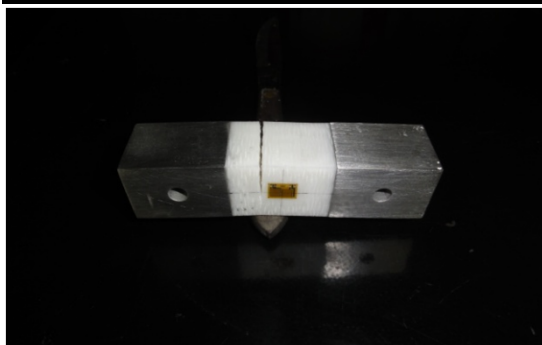
Thickness: 1.50 in
 Side 1: 1.00 in
 Side 2: 1.00 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,611 lbs
 20% Max Load: 644 lbs

PICTURE OF SPECIMEN PRE-TEST

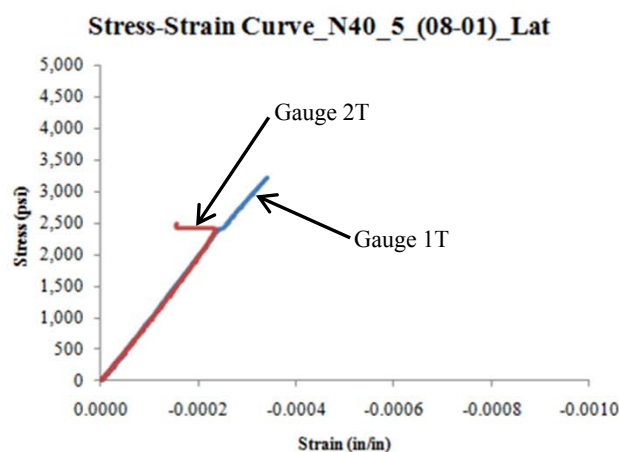
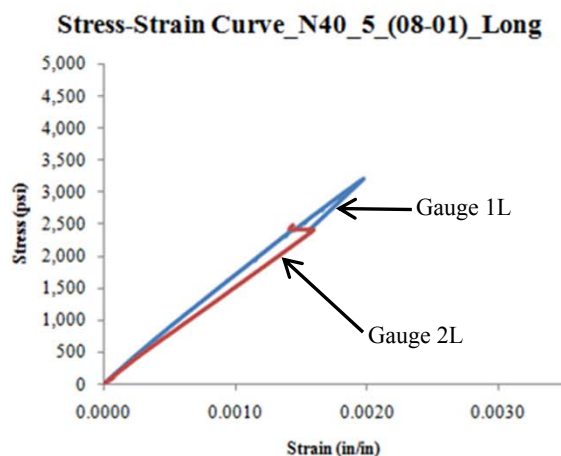


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000934 | 0.000350 | 1T | -0.000166 | -0.000068 | 0.1667 |
| 2L | 0.001062 | 0.000402 | 2T | -0.000169 | -0.000071 | 0.1493 |
| Average | | | | | | 0.1580 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-70-FY08

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured:

Average Material Properties (5 Specimens):

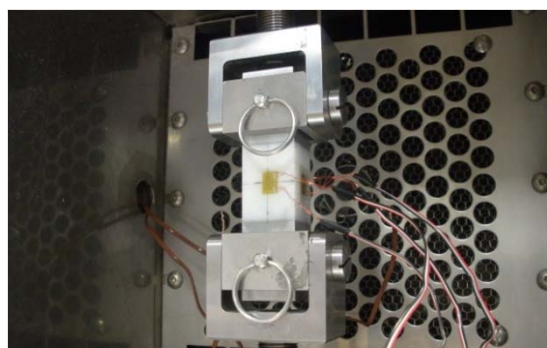
Poisson’s Ratio, ν_{xz} : 0.1847

Maximum Load, P_z : 3,649 lbs

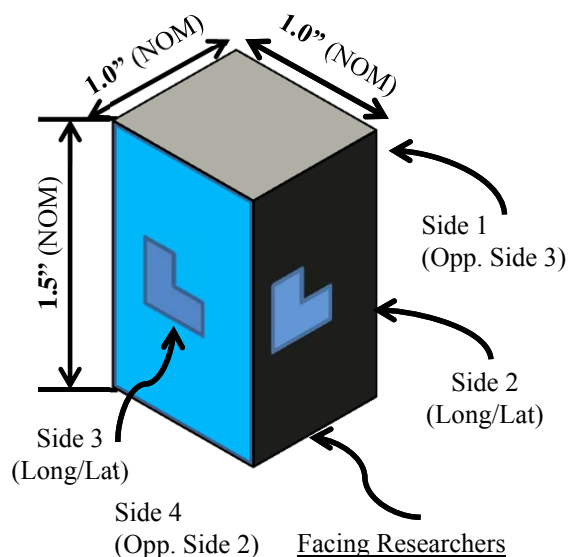
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio ν_{xz} | Failure Mode |
|----------------|-------------------|-------------------------|-------------------------------|--------------|
| 1 | MAT1-OP-1-70-FY08 | 3,484 | 0.1856 | Rupture |
| 2 | MAT1-OP-2-70-FY08 | 3,822 | 0.2021 | Bondline |
| 3 | MAT1-OP-3-70-FY08 | 3,752 | 0.1679 | Bondline |
| 4 | MAT1-OP-4-70-FY08 | 4,058 | 0.2193 | Bondline |
| 5 | MAT1-OP-5-70-FY08 | 3,130 | 0.1488 | Rupture |
| Average | | 3,649 | 0.1847 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) Reference G-32 thru G-36 for individual specimen data.
- 2) 8 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-70-FY08**
 Test Date: 3/7/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

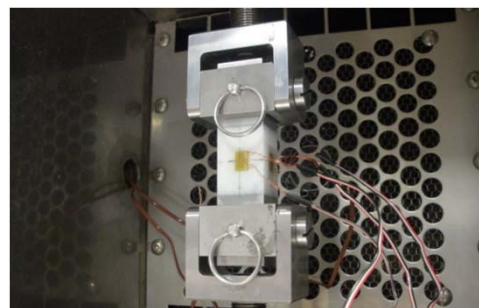
Average Material Properties:

Maximum Load, P_z : 3,484 lbs
 Poisson's Ratio, v_{xz} : 0.1856

Measured Specimen Dimensions:

Thickness: 1.5 in
 Side 1: 1.000 in
 Side 2: 1.001 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,742 lbs
 20% Max Load: 697 lbs

PICTURE OF SPECIMEN PRE-TEST

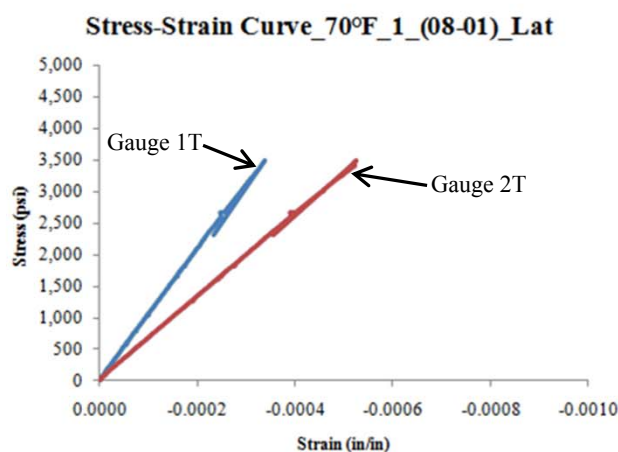
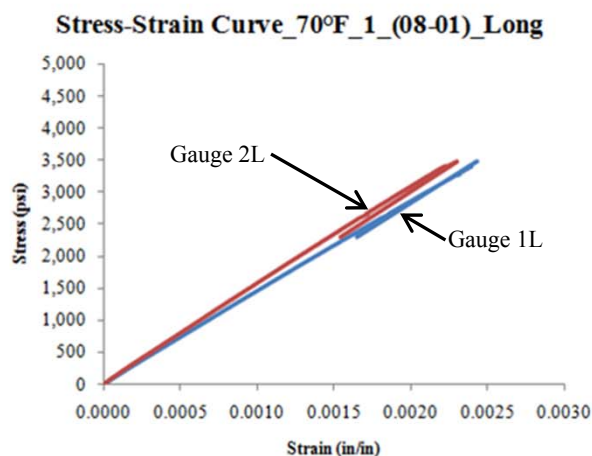


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001192 | 0.000468 | 1T | -0.000165 | -0.000066 | 0.1373 |
| 2L | 0.001102 | 0.000430 | 2T | -0.000261 | -0.000103 | 0.2339 |
| Average | | | | | | 0.1856 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-70-FY08**
 Test Date: 3/9/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,822 lbs
 Poisson's Ratio, v_{xz} : 0.2021

Measured Specimen Dimensions:

Thickness: 1.5 in
 Side 1: 1.003 in
 Side 2: 1.000 in

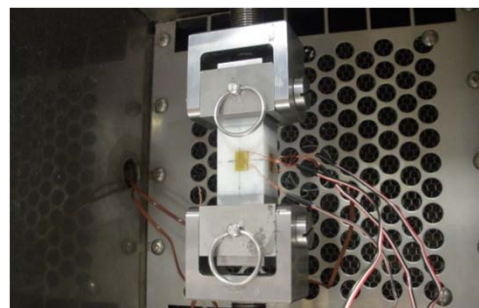
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,911 lbs

20% Max Load: 764 lbs

PICTURE OF SPECIMEN PRE-TEST

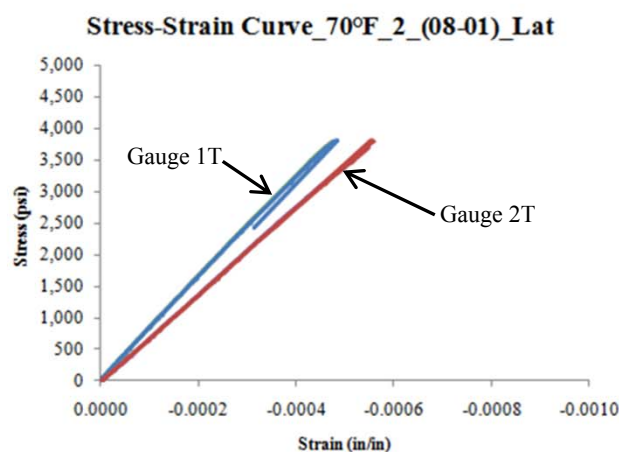
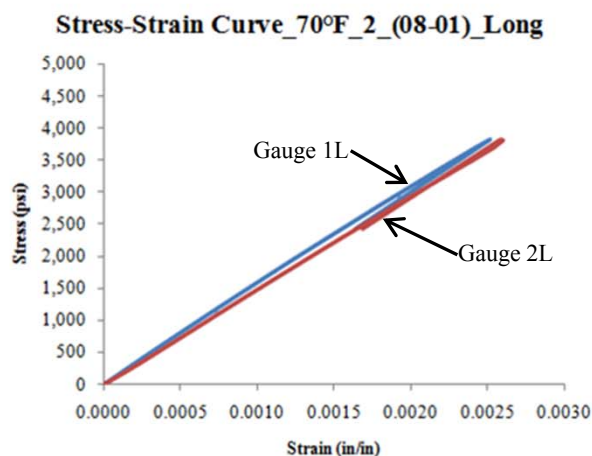


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001206 | 0.000471 | 1T | -0.000232 | -0.000092 | 0.1902 |
| 2L | 0.001290 | 0.000523 | 2T | -0.000279 | -0.000115 | 0.2140 |
| Average | | | | | | 0.2021 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-70-FY08**
 Test Date: 3/9/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

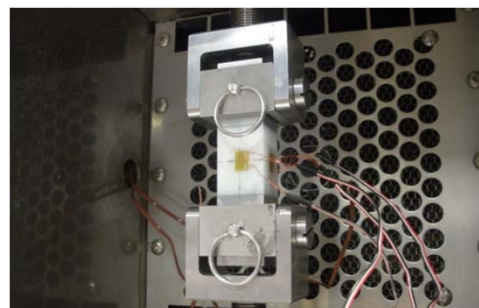
Maximum Load, P_z : 3,752 lbs
 Poisson's Ratio, v_{xz} : 0.1679

Measured Specimen Dimensions:

Thickness: 1.5 in
 Side 1: 0.995 in
 Side 2: 0.994 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,876 lbs
 20% Max Load: 750 lbs

PICTURE OF SPECIMEN PRE-TEST

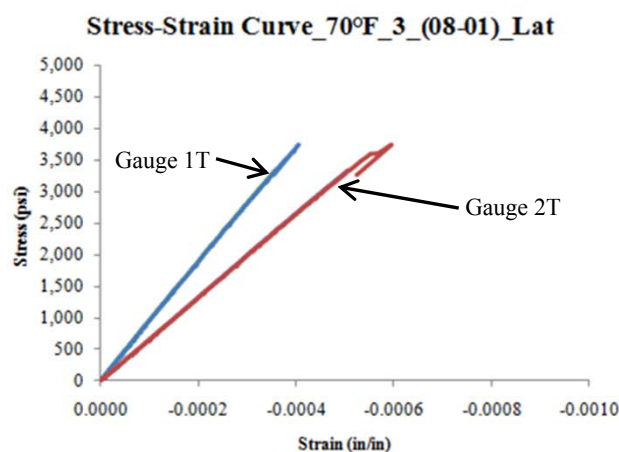
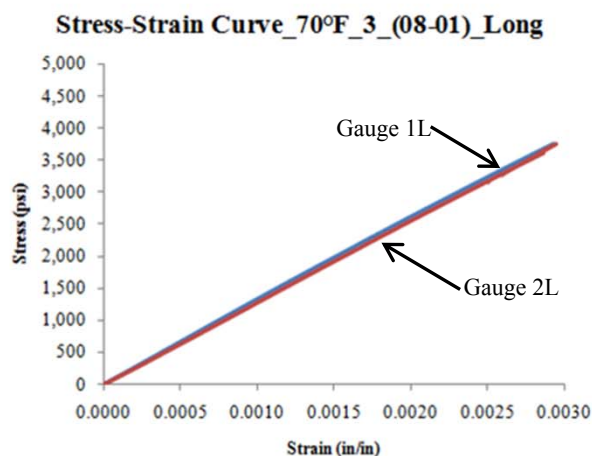


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001418 | 0.000563 | 1T | -0.000199 | -0.000077 | 0.1418 |
| 2L | 0.001468 | 0.000595 | 2T | -0.000284 | -0.000114 | 0.1941 |
| Average | | | | | | 0.1679 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-70-FY08**
 Test Date: 3/9/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

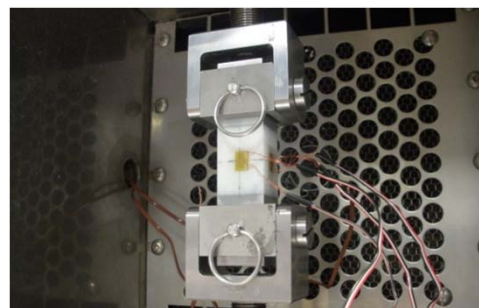
Average Material Properties:

Maximum Load, P_z : 4,058 lbs
 Poisson's Ratio, v_{xz} : 0.2193

Measured Specimen Dimensions:

Thickness: 1.5 in
 Side 1: 1.003 in
 Side 2: 0.998 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 2,029 lbs
 20% Max Load: 812 lbs

PICTURE OF SPECIMEN PRE-TEST

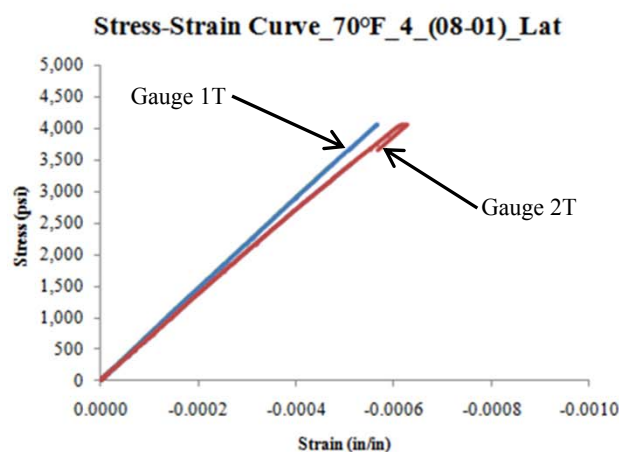
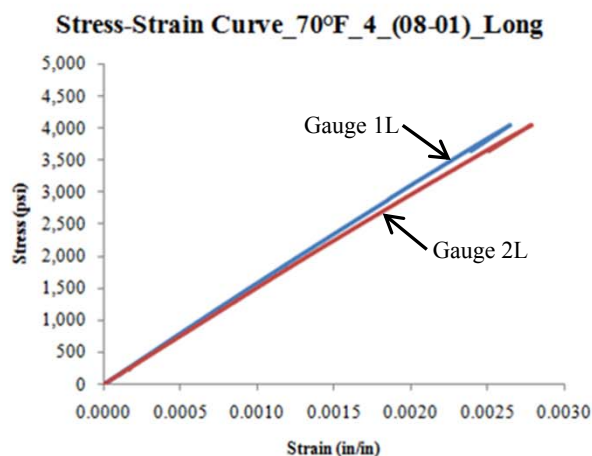


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001283 | 0.000505 | 1T | -0.000278 | -0.000109 | 0.2171 |
| 2L | 0.001343 | 0.000534 | 2T | -0.000297 | -0.000117 | 0.2214 |
| Average | | | | | | 0.2193 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-70-FY08**
 Test Date: 3/21/2011
 Specimen Received: 2/15/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,130 lbs
 Poisson's Ratio, v_{xz} : 0.1488

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 1.000 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,565 lbs
 20% Max Load: 626 lbs

PICTURE OF SPECIMEN PRE-TEST

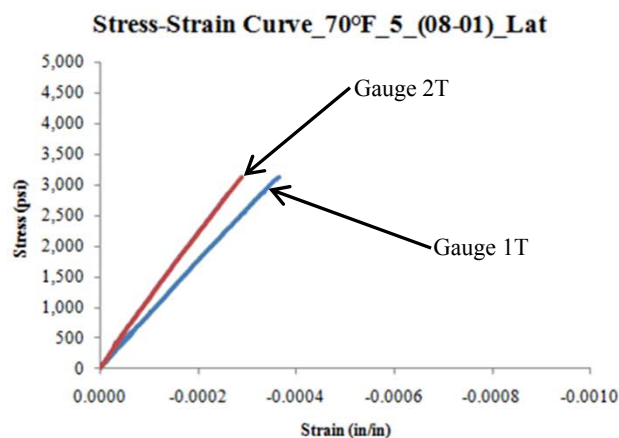
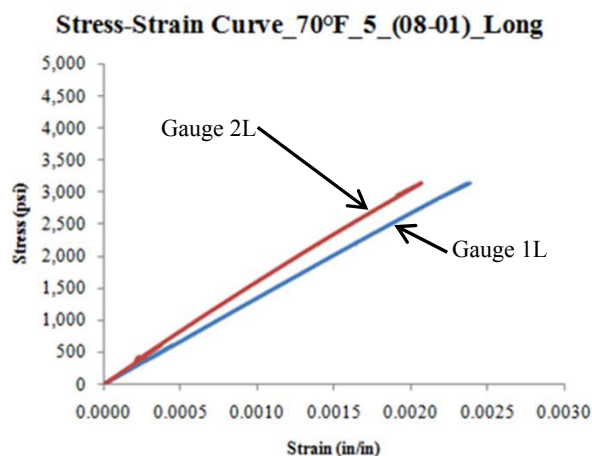


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001167 | 0.000470 | 1T | -0.000178 | -0.000070 | 0.1544 |
| 2L | 0.000976 | 0.000373 | 2T | -0.000139 | -0.000052 | 0.1433 |
| Average | | | | | | 0.1488 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-140-FY08
 Material: Epoxy Resin SC-15, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1192
 Maximum Load, P_z : 1,415 lbs

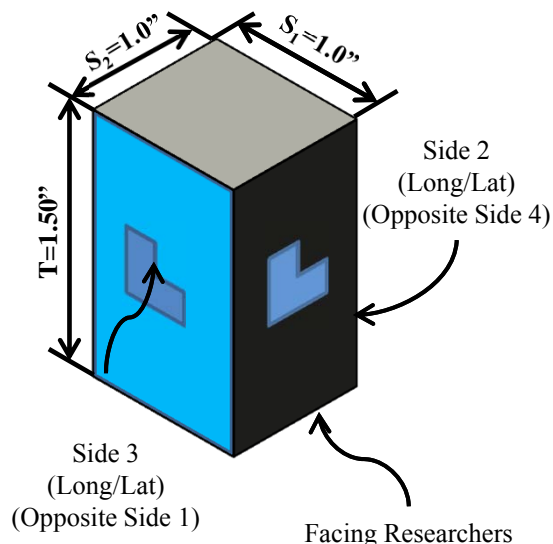
| Specimen | Max Load, P_z (lbs) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|--------------------|--------------------------|--------------------------------|--------------|
| MAT1-OP-1-140-FY08 | 1,398 | 0.1372 | Bondline |
| MAT1-OP-2-140-FY08 | 1,439 | 0.1113 | Bondline |
| MAT1-OP-3-140-FY08 | 1,372 | 0.1131 | Bondline |
| MAT1-OP-4-140-FY08 | 1,383 | 0.1274 | Bondline |
| MAT1-OP-5-140-FY08 | 1,484 | 0.1071 | Bondline |
| Average | 1,415 | 0.1192 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) Reference G-32 thru G-36 for individual specimen data.
- 2) 8 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-140-FY08**
 Test Date: 8/24/2011
 Specimen Received: 8/17/2011
 Properties Measured: v_{xz}

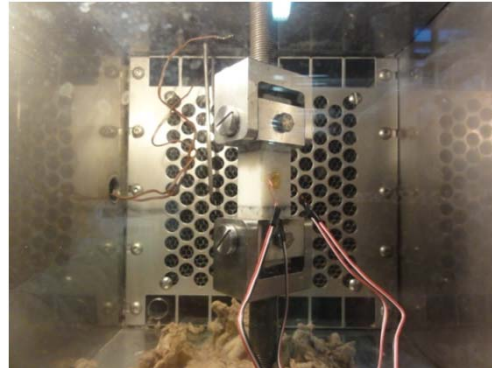
Average Material Properties:

Maximum Load, P_z : 1,398 lbs
 Poisson's Ratio, v_{xz} : 0.1372

Measured Specimen Dimensions:

Thickness: 1.380 in
 Side 1: 0.997 in
 Side 2: 1.000 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 35% Max Load: 1,360 lbs
 10% Max Load: 388 lbs

PICTURE OF SPECIMEN PRE-TEST



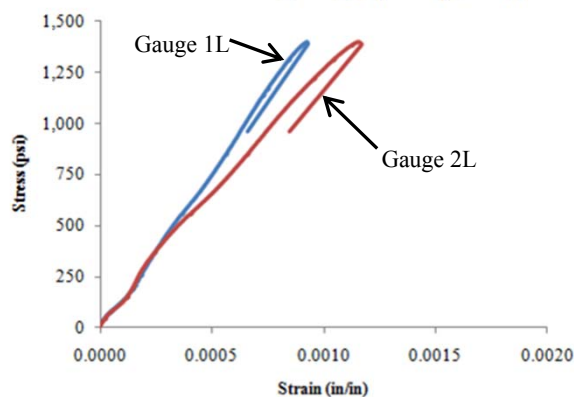
PICTURE OF SPECIMEN POST-TEST



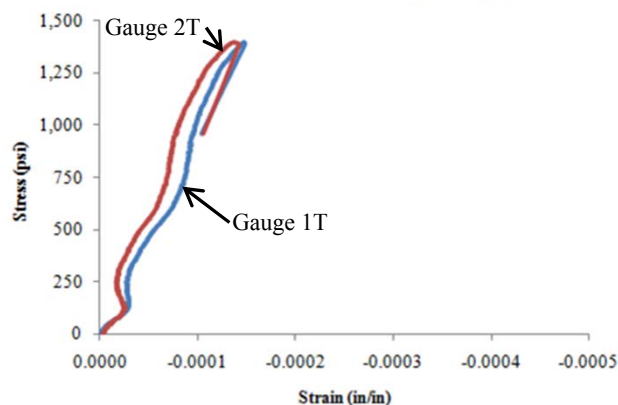
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.000885 | 0.000255 | 1T | -0.000139 | -0.000040 | 0.1561 |
| 2L | 0.001096 | 0.000257 | 2T | -0.000127 | -0.000028 | 0.1184 |
| Average | | | | | | 0.1372 |

Stress-Strain Curve_140_1_(08-01)_Long



Stress-Strain Curve_140_1_(08-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 35% of max load based on tensile strength measured in the MAT1-TZ-140-FY08 data.
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-140-FY08**
 Test Date: 8/24/2011
 Specimen Received: 8/17/2011
 Properties Measured: v_{xz}

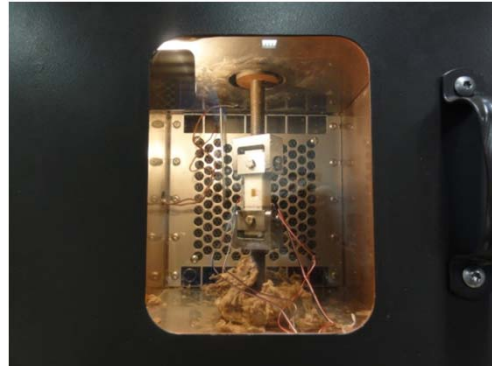
Average Material Properties:

Maximum Load, P_z : 1,439 lbs
 Poisson's Ratio, v_{xz} : 0.1113

Measured Specimen Dimensions:

Thickness: 1.380 in
 Side 1: 1.001 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 35% Max Load: 1,360 lbs
 10% Max Load: 388 lbs

PICTURE OF SPECIMEN PRE-TEST



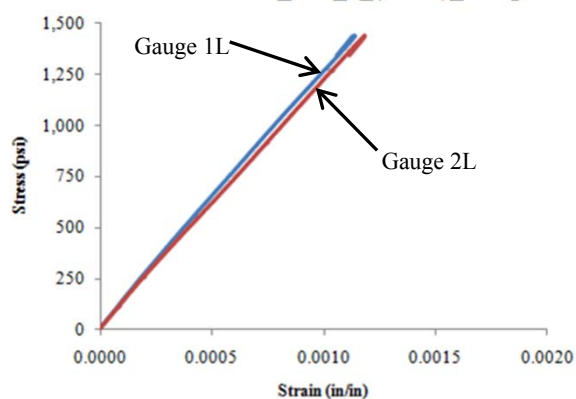
PICTURE OF SPECIMEN POST-TEST



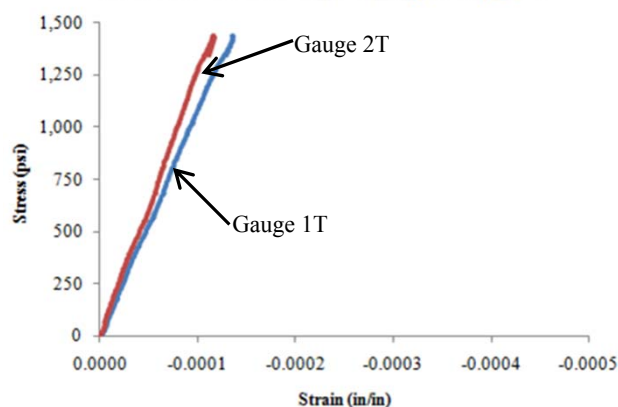
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001074 | 0.000287 | 1T | -0.000132 | -0.000035 | 0.1225 |
| 2L | 0.001111 | 0.000304 | 2T | -0.000111 | -0.000030 | 0.1000 |
| Average | | | | | | 0.1113 |

Stress-Strain Curve_140_2_(08-01)_Long



Stress-Strain Curve_140_2_(08-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 35% of max load based on tensile strength measured in the MAT1-TZ-140-FY08 data.
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-140-FY08**
 Test Date: 8/24/2011
 Specimen Received: 8/17/2011
 Properties Measured: v_{xz}

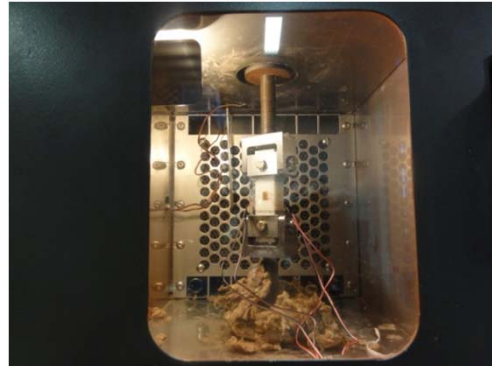
Average Material Properties:

Maximum Load, P_z : 1,372 lbs
 Poisson's Ratio, v_{xz} : 0.1131

Measured Specimen Dimensions:

Thickness: 1.380 in
 Side 1: 1.000 in
 Side 2: 1.002 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 35% Max Load: 1,360 lbs
 10% Max Load: 388 lbs

PICTURE OF SPECIMEN PRE-TEST



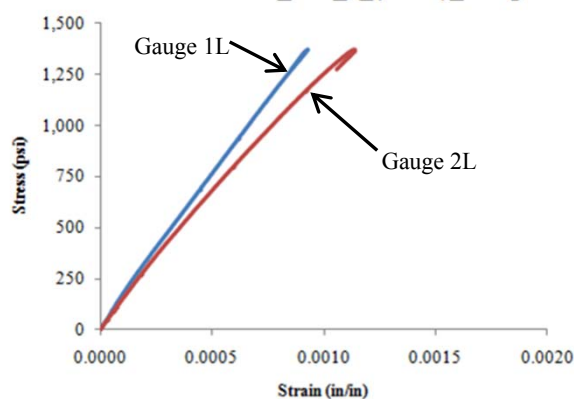
PICTURE OF SPECIMEN POST-TEST



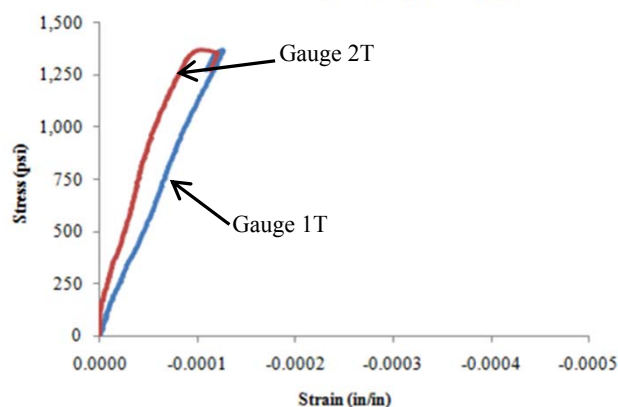
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.000918 | 0.000237 | 1T | -0.000125 | -0.000033 | 0.1344 |
| 2L | 0.001115 | 0.000267 | 2T | -0.000095 | -0.000017 | 0.0919 |
| Average | | | | | | 0.1131 |

Stress-Strain Curve_140_3_(08-01)_Long



Stress-Strain Curve_140_3_(08-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 35% of max load based on tensile strength measured in the MAT1-TZ-140-FY08 data.
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-140-FY08**
 Test Date: 8/24/2011
 Specimen Received: 8/17/2011
 Properties Measured: v_{xz}

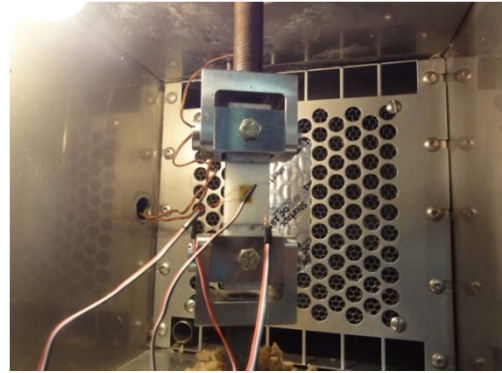
Average Material Properties:

Maximum Load, P_z : 1,383 lbs
 Poisson's Ratio, v_{xz} : 0.1274

Measured Specimen Dimensions:

Thickness: 1.380 in
 Side 1: 1.001 in
 Side 2: 1.000 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 35% Max Load: 1,360 lbs
 10% Max Load: 388 lbs

PICTURE OF SPECIMEN PRE-TEST



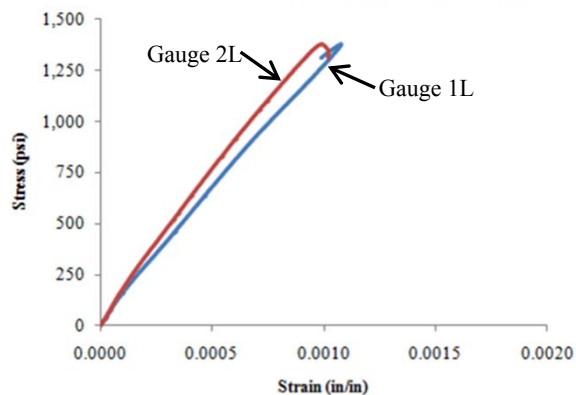
PICTURE OF SPECIMEN POST-TEST



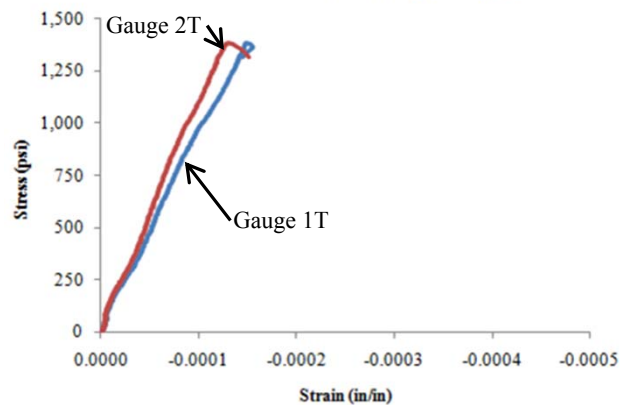
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001066 | 0.000275 | 1T | -0.000146 | -0.000041 | 0.1320 |
| 2L | 0.000955 | 0.000232 | 2T | -0.000126 | -0.000037 | 0.1229 |
| Average | | | | | | 0.1274 |

Stress-Strain Curve_140_4_(08-01)_Long



Stress-Strain Curve_140_4_(08-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 35% of max load based on tensile strength measured in the MAT1-TZ-140-FY08 data.
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-140-FY08**
 Test Date: 8/24/2011
 Specimen Received: 8/17/2011
 Properties Measured: v_{xz}

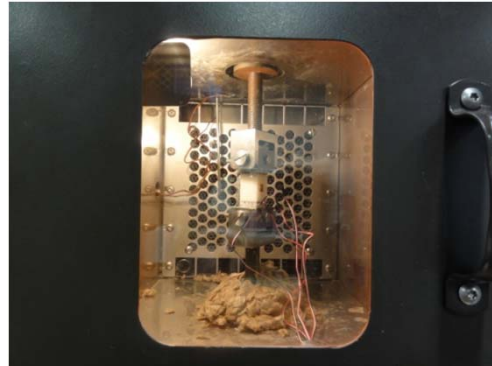
Average Material Properties:

Maximum Load, P_z : 1,484 lbs
 Poisson's Ratio, v_{xz} : 0.1071

Measured Specimen Dimensions:

Thickness: 1.380 in
 Side 1: 1.001 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 35% Max Load: 1,360 lbs
 10% Max Load: 388 lbs

PICTURE OF SPECIMEN PRE-TEST



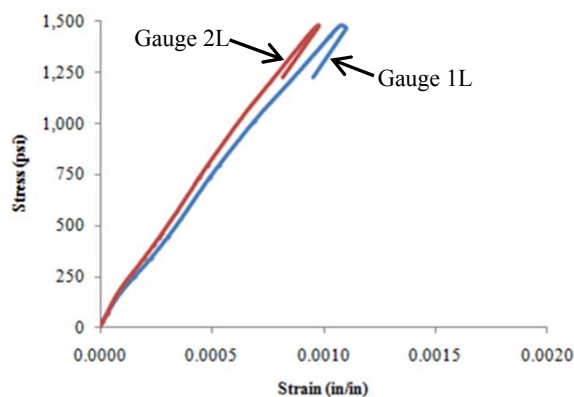
PICTURE OF SPECIMEN POST-TEST



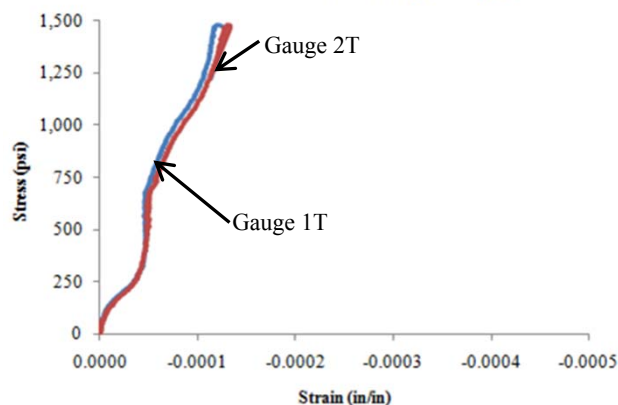
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 35% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.000971 | 0.000263 | 1T | -0.000113 | -0.000046 | 0.0959 |
| 2L | 0.000876 | 0.000229 | 2T | -0.000122 | -0.000045 | 0.1183 |
| Average | | | | | | 0.1071 |

Stress-Strain Curve_140_5_(08-01)_Long



Stress-Strain Curve_140_5_(08-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 35% of max load based on tensile strength measured in the MAT1-TZ-140-FY08 data.
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX C

MATERIAL 2-FY08 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

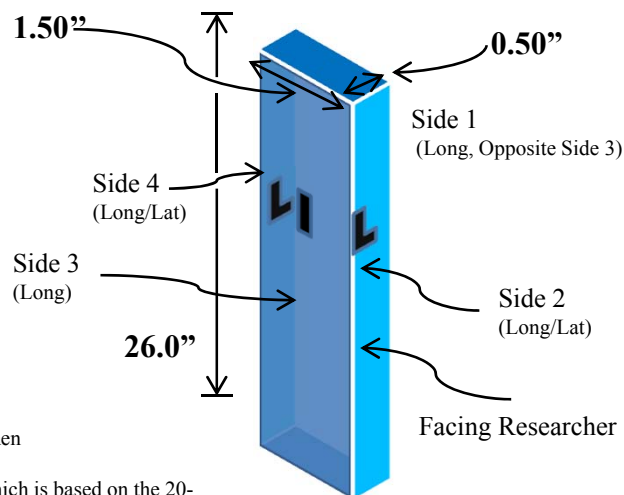
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TX-N40-FY08
Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
Nominal Temperature: -40°F
Properties Measured: ST_x , E_x , v_{xy}
Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 37,135 lbs
 Tensile Strength, ST_x : 54,330 psi
 Tensile Modulus, E_x : 2,286,416 psi
 Ultimate Strain, ϵ_x : 0.0238 in/in
 Poisson's Ratio, v_{xy} : 0.1886

| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, v_{xy} | Failure Mode |
|----------------|--------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|---------------------------|--------------|
| 1 | MAT2-TX-1-N40-FY08 | 37,233 | 55,360 | 2,381,334 | 0.0232 | 0.2196 | SGM |
| 2 | MAT2-TX-2-N40-FY08 | 36,982 | 55,037 | 2,245,998 | 0.0245 | 0.1964 | SGM |
| 3 | MAT2-TX-3-N40-FY08 | 36,891 | 50,021 | 2,142,034 | 0.0234 | 0.2354 | SGM |
| 4 | MAT2-TX-4-N40-FY08 | 37,134 | 55,503 | 2,263,263 | 0.0245 | 0.1213 | SGM |
| 5 | MAT2-TX-5-N40-FY08 | 37,434 | 55,731 | 2,399,450 | 0.0232 | 0.1702 | SGM |
| Average | | 37,135 | 54,330 | 2,286,416 | 0.0238 | 0.1886 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) SGM corresponds with S=long splitting, G=gauge area, M=middle of specimen
- 3) See C-2 to C-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-N40-FY08**
 Test Date: 11/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 37,233 lbs
 Tensile Strength, ST_x : 55,360 psi
 Tensile Modulus, E_x : 2,381,334 psi
 Ultimate Strain, ϵ_x : 0.0232 in/in
 Poisson's Ratio, v_{xy} : 0.2196

Measured Specimen Dimensions:

Width, W: 0.4961 in
 Thickness, H: 1.3557 in
 Laboratory Temperature: 68°F
 Failure Mode: SGM
 20% Max Load: 7,447 lbs
 50% Max Load: 18,617 lbs

PICTURE OF SPECIMEN PRE-TEST



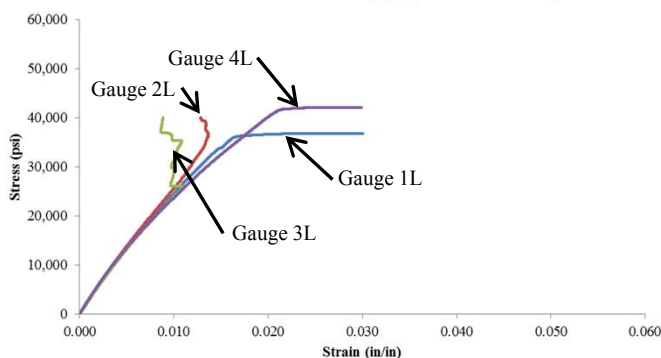
PICTURE OF SPECIMEN POST-TEST



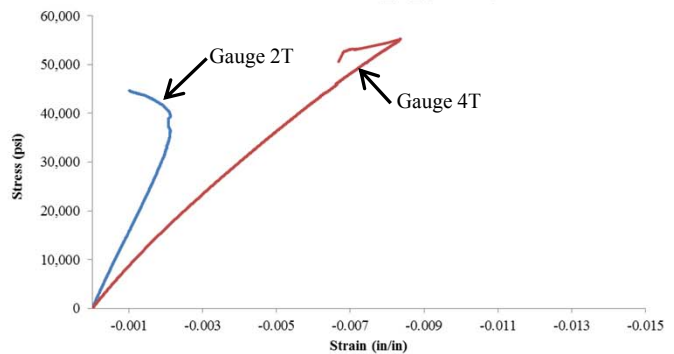
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0115 | 0.0040 | 2,226,698 | | | | |
| 2L | 0.0109 | 0.0039 | 2,389,031 | 2T | -0.0017 | -0.0007 | 0.1528 |
| 3L | 0.0098 | 0.0041 | 2,884,171 | | | | |
| 4L | 0.0121 | 0.0039 | 2,025,437 | 4T | -0.0036 | -0.0013 | 0.2863 |
| Average | | | 2,381,334 | | | | 0.2196 |

Stress-Strain Curve N40_1_(08-02), Long.



Stress-Strain Curve N40_1_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as SGM for long splitting originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-N40-FY08**
 Test Date: 11/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , v_{xy}

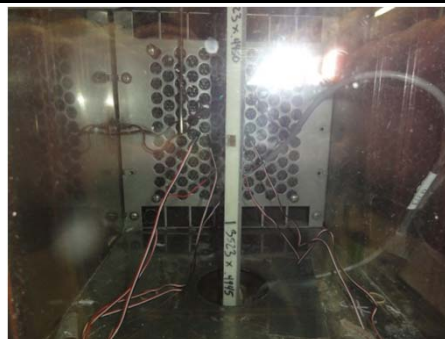
Average Material Properties:

Ultimate Load, P_x : 36,982 lbs
 Tensile Strength, ST_x : 55,037 psi
 Tensile Modulus, E_x : 2,245,998 psi
 Ultimate Strain, ϵ_x : 0.0245 in/in
 Poisson's Ratio, v_{xy} : 0.1964

Measured Specimen Dimensions:

Width, W: 0.4955 in
 Thickness, H: 1.3563 in
 Laboratory Temperature: 68°F
 Failure Mode: SGM
 20% Max Load: 7,396 lbs
 50% Max Load: 18,491 lbs

PICTURE OF SPECIMEN PRE-TEST



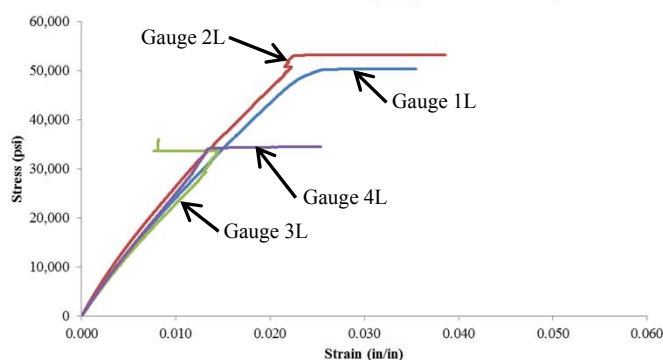
PICTURE OF SPECIMEN POST-TEST



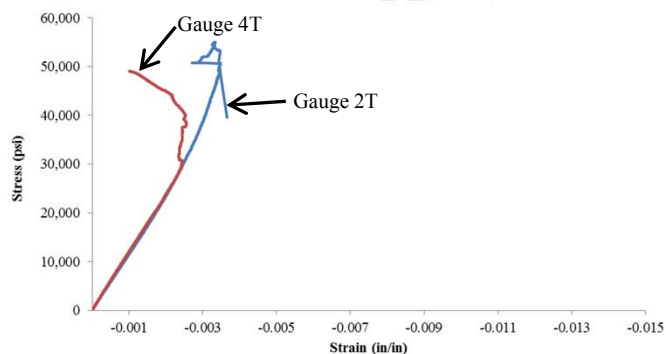
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0117 | 0.0041 | 2,188,623 | | | | |
| 2L | 0.0105 | 0.0036 | 2,391,305 | 2T | -0.0023 | -0.0010 | 0.1952 |
| 3L | 0.0124 | 0.0043 | 2,049,921 | | | | |
| 4L | 0.0111 | 0.0041 | 2,354,144 | 4T | -0.0023 | -0.0009 | 0.1977 |
| Average | | | 2,245,998 | | | | 0.1964 |

Stress-Strain Curve N40_2_(08-02), Long.



Stress-Strain Curve N40_2_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as SGM for long splitting originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-N40-FY08**
 Test Date: 11/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , v_{xy}

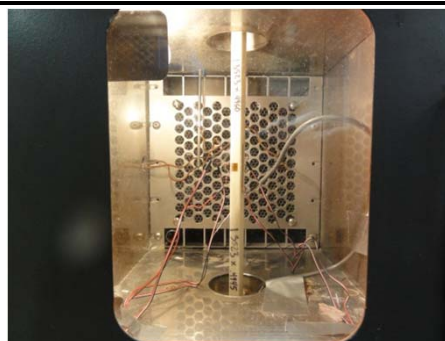
Average Material Properties:

Ultimate Load, P_x : 36,891 lbs
 Tensile Strength, ST_x : 50,021 psi
 Tensile Modulus, E_x : 2,142,034 psi
 Ultimate Strain, ϵ_x : 0.0234 in/in
 Poisson's Ratio, v_{xy} : 0.2354

Measured Specimen Dimensions:

Width, W: 0.5207 in
 Thickness, H: 1.4164 in
 Laboratory Temperature: 68°F
 Failure Mode: SGM
 20% Max Load: 7,378 lbs
 50% Max Load: 18,446 lbs

PICTURE OF SPECIMEN PRE-TEST



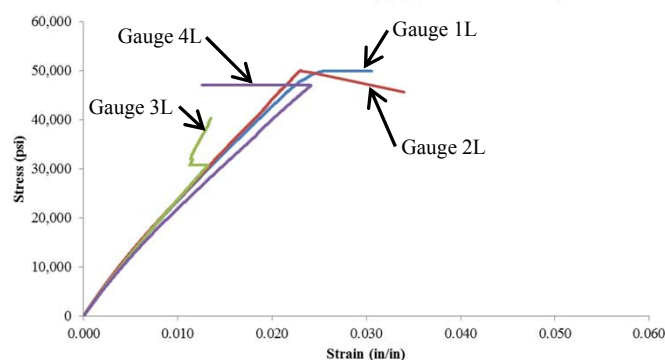
PICTURE OF SPECIMEN POST-TEST



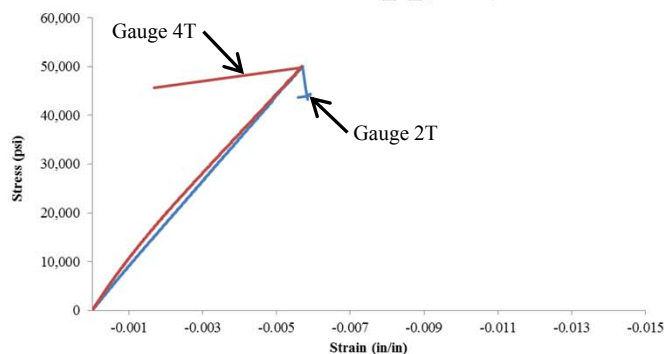
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0107 | 0.0038 | 2,168,239 | | | | |
| 2L | 0.0106 | 0.0037 | 2,173,373 | 2T | -0.0028 | -0.0011 | 0.2496 |
| 3L | 0.0106 | 0.0039 | 2,255,869 | | | | |
| 4L | 0.0117 | 0.0041 | 1,970,656 | 4T | -0.0026 | -0.0009 | 0.2212 |
| Average | | | 2,142,034 | | | | 0.2354 |

Stress-Strain Curve N40_3_(08-02), Long.



Stress-Strain Curve N40_3_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as SGM for long splitting originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-N40-FY08**
 Test Date: 11/3/2011
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , ν_{xy}

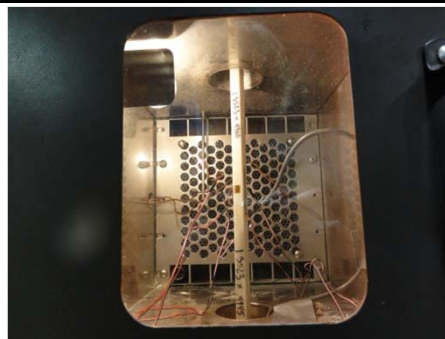
Average Material Properties:

Ultimate Load, P_x : 37,134 lbs
 Tensile Strength, ST_x : 55,503 psi
 Tensile Modulus, E_x : 2,263,263 psi
 Ultimate Strain, ϵ_x : 0.0245 in/in
 Poisson's Ratio, ν_{xy} : 0.1213

Measured Specimen Dimensions:

Width, W: 0.4948 in
 Thickness, H: 1.3523 in
 Laboratory Temperature: 68°F
 Failure Mode: SGM
 20% Max Load: 7,427 lbs
 50% Max Load: 18,567 lbs

PICTURE OF SPECIMEN PRE-TEST



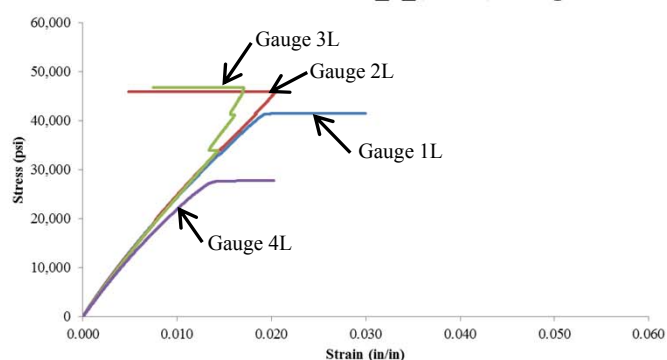
PICTURE OF SPECIMEN POST-TEST



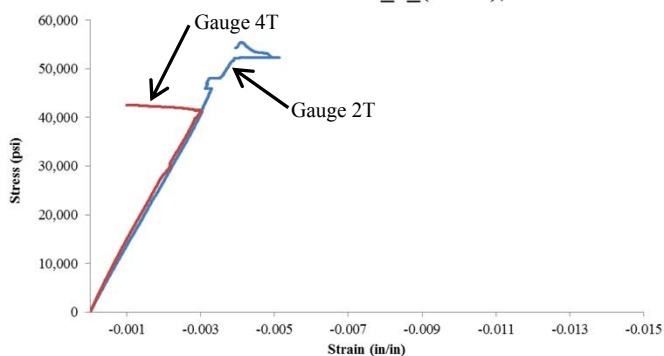
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0117 | 0.0041 | 2,193,958 | | | | |
| 2L | 0.0114 | 0.0042 | 2,301,947 | 2T | -0.0021 | -0.0008 | 0.1743 |
| 3L | 0.0115 | 0.0042 | 2,293,883 | | | | |
| 4L | 0.0224 | 0.0045 | 934,198 | 4T | -0.0019 | -0.0007 | 0.0683 |
| Average | | | 2,263,263 | | | | 0.1213 |

Stress-Strain Curve N40_4_(08-02), Long.



Stress-Strain Curve N40_4_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as SGM for long splitting originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *The averaged tensile modulus reported for this test does not include gauge 4L due to its nonlinear behavior through the 20 – 50% range

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-N40-FY08**
 Test Date: 11/3/2011
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , ν_{xy}

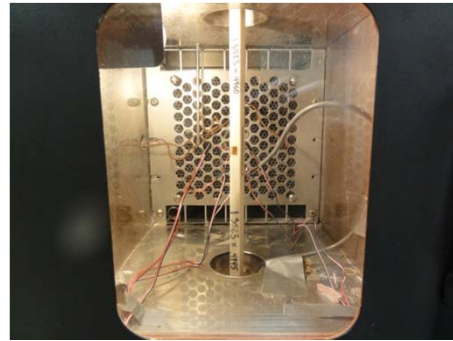
Average Material Properties:

Ultimate Load, P_x : 37,434 lbs
 Tensile Strength, ST_x : 55,731 psi
 Tensile Modulus, E_x : 2,399,450 psi
 Ultimate Strain, ϵ_x : 0.0232 in/in
 Poisson's Ratio, ν_{xy} : 0.1702

Measured Specimen Dimensions:

Width, W: 0.4959 in
 Thickness, H: 1.3545 in
 Laboratory Temperature: 68°F
 Failure Mode: SGM
 20% Max Load: 7,487 lbs
 50% Max Load: 18,717 lbs

PICTURE OF SPECIMEN PRE-TEST



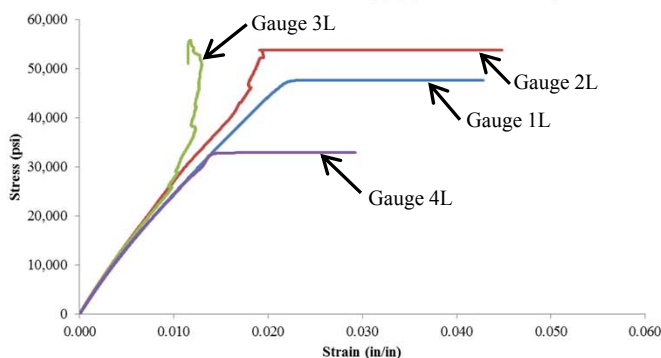
PICTURE OF SPECIMEN POST-TEST



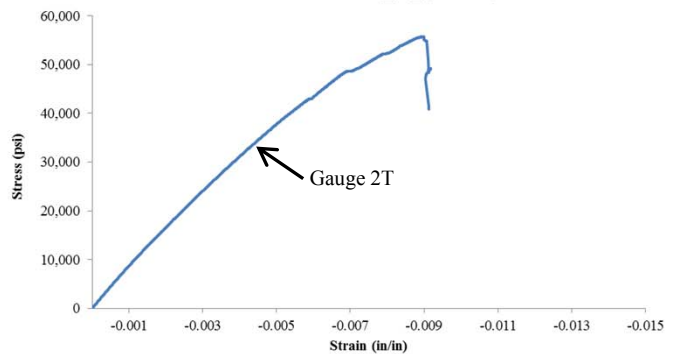
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0116 | 0.0041 | 2,220,515 | | | | |
| 2L | 0.0103 | 0.0038 | 2,549,594 | 2T | -0.0035 | -0.0013 | 0.3402 |
| 3L | 0.0101 | 0.0038 | 2,670,158 | | | | |
| 4L | 0.0118 | 0.0040 | 2,157,532 | 4T | Lost Gauge | | (LG) |
| Average | | | 2,399,450 | | | | 0.3402 |

Stress-Strain Curve N40_5_(08-02), Long.



Stress-Strain Curve N40_5_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as SGM for long splitting originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

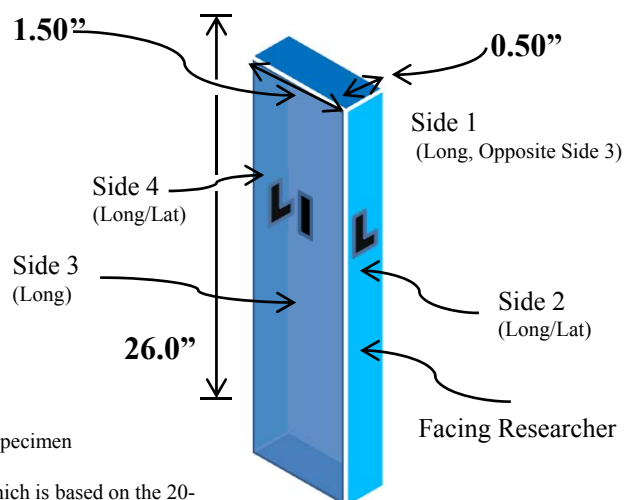
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-TX-70-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **ST_x, E_x, v_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **30,411** **lbs**
 Tensile Strength, ST_x: **45,226** **psi**
 Tensile Modulus, E_x: **1,986,367** **psi**
 Ultimate Strain, ε_x: **0.0228** **in/in**
 Poisson's Ratio, v_{xy}: **0.2110**

| Sample | Specimen | Ultimate Load, P _x (lbs) | Tensile Strength, ST _x (psi) | Tensile Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, v _{xy} | Failure Mode |
|----------------|-------------------|-------------------------------------|---|---------------------------------------|---|----------------------------------|--------------|
| 1 | MAT2-TX-1-70-FY08 | 30,849 | 44,775 | 1,925,162 | 0.0233 | 0.2150 | DGM |
| 2 | MAT2-TX-2-70-FY08 | 32,136 | 45,551 | 1,812,337 | 0.0251 | 0.1549 | DGM |
| 3 | MAT2-TX-3-70-FY08 | 30,420 | 44,038 | 2,049,681 | 0.0215 | 0.2282 | DGM |
| 4 | MAT2-TX-4-70-FY08 | 29,398 | 45,587 | 1,995,342 | 0.0228 | 0.1837 | DGM |
| 5 | MAT2-TX-5-70-FY08 | 29,253 | 46,177 | 2,149,310 | 0.0215 | 0.2735 | DGM |
| Average | | 30,411 | 45,226 | 1,986,367 | 0.0228 | 0.2110 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See C-8 to C-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-70-FY08**
 Test Date: 10/13/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,849 lbs
 Tensile Strength, ST_x : 44,775 psi
 Tensile Modulus, E_x : 1,925,162 psi
 Ultimate Strain, ϵ_x : 0.0233 in/in
 Poisson's Ratio, v_{xy} : 0.2150

Measured Specimen Dimensions:

Width, W: 0.4923 in
 Thickness, H: 1.3995 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,170 lbs
 50% Max Load: 15,424 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

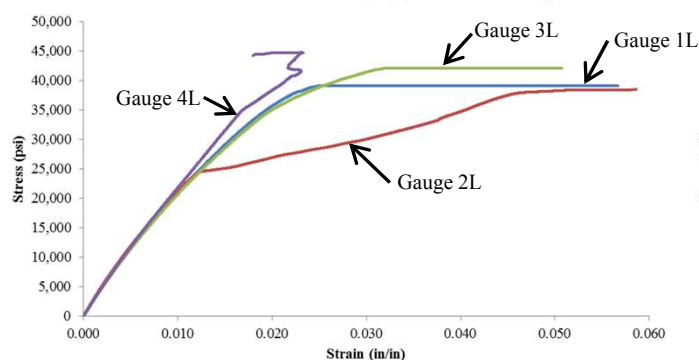


PICTURE OF SPECIMEN POST-TEST

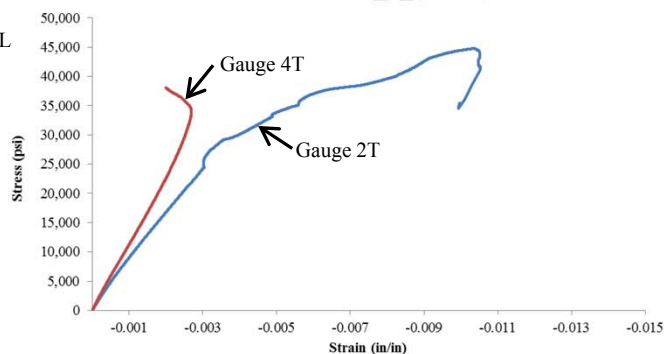


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0108 | 0.0038 | 1,911,736 | | | | |
| 2L | 0.0107 | 0.0036 | 1,883,494 | 2T | -0.0028 | -0.0010 | 0.2479 |
| 3L | 0.0110 | 0.0038 | 1,864,967 | 3T | -0.0031 | -0.0013 | 0.2520 |
| 4L | 0.0103 | 0.0037 | 2,040,451 | 4T | -0.0020 | -0.0008 | 0.1820 |
| Average | | | 1,925,162 | | | | 0.2150 |

Stress-Strain Curve 70_1_(08-02), Long.



Stress-Strain Curve 70_1_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-70-FY08**
 Test Date: 10/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 32,136 lbs
 Tensile Strength, ST_x : 45,551 psi
 Tensile Modulus, E_x : 1,812,337 psi
 Ultimate Strain, ϵ_x : 0.0251 in/in
 Poisson's Ratio, v_{xy} : 0.1549

Measured Specimen Dimensions:

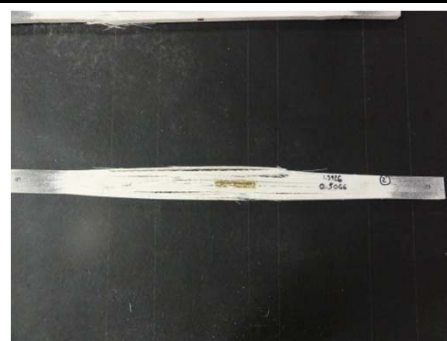
Width, W: 0.5066 in
 Thickness, H: 1.3926 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,427 lbs
 50% Max Load: 16,068 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

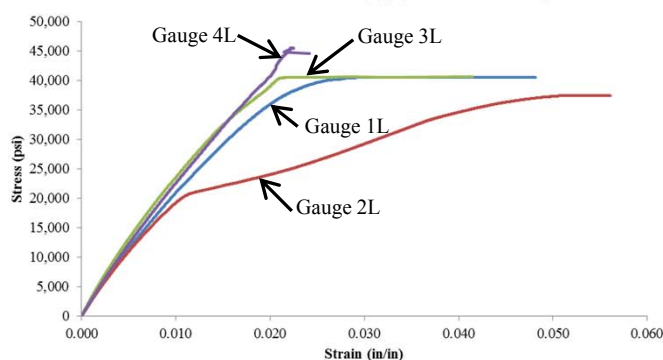


PICTURE OF SPECIMEN POST-TEST

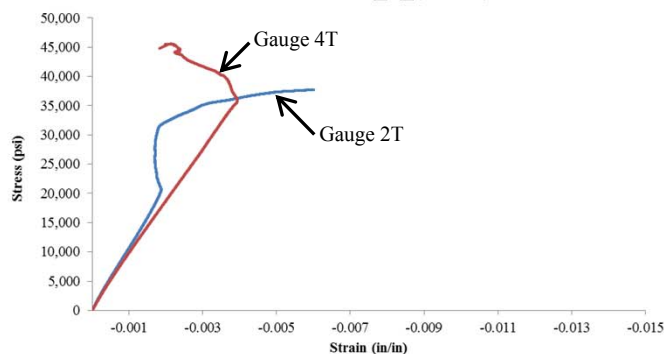


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0111 | 0.0039 | 1,902,566 | | | | |
| 2L | 0.0169 | 0.0040 | 1,063,737 | 2T | -0.0018 | -0.0008 | 0.0710 |
| 3L | 0.0096 | 0.0033 | 2,171,693 | 3T | -0.0028 | -0.0012 | 0.2470 |
| 4L | 0.0101 | 0.0036 | 2,111,352 | 4T | -0.0025 | -0.0009 | 0.2388 |
| Average | | | 1,812,337 | | | | 0.1549 |

Stress-Strain Curve 70_2_(08-02), Long.



Stress-Strain Curve 70_2_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-70-FY08**
 Test Date: 10/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 30,420 lbs
 Tensile Strength, ST_x : 44,038 psi
 Tensile Modulus, E_x : 2,049,681 psi
 Ultimate Strain, ϵ_x : 0.0215 in/in
 Poisson's Ratio, v_{xy} : 0.2282

Measured Specimen Dimensions:

Width, W: 0.4905 in
 Thickness, H: 1.4083 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 6,084 lbs
 50% Max Load: 15,210 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

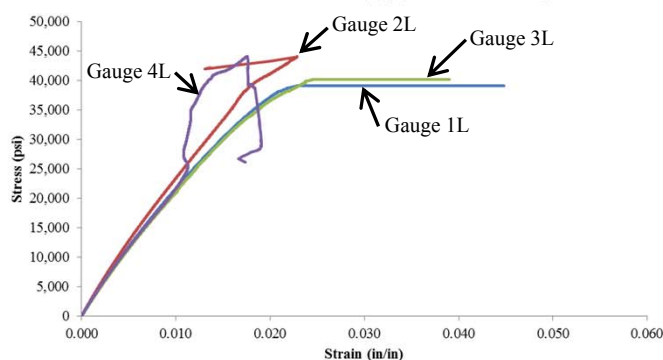


PICTURE OF SPECIMEN POST-TEST

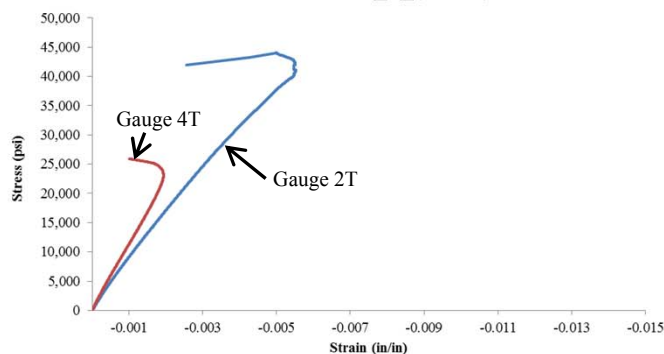


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0102 | 0.0036 | 2,007,425 | | | | |
| 2L | 0.0093 | 0.0033 | 2,204,578 | 2T | -0.0026 | -0.0010 | 0.2814 |
| 3L | 0.0105 | 0.0038 | 1,961,408 | 3T | -0.0030 | -0.0013 | 0.2549 |
| 4L | 0.0102 | 0.0037 | 2,025,314 | 4T | -0.0019 | -0.0008 | 0.1750 |
| Average | | | 2,049,681 | | | | 0.2282 |

Stress-Strain Curve 70_3_(08-02), Long.



Stress-Strain Curve 70_3_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-70-FY08**
 Test Date: 10/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 29,398 lbs
 Tensile Strength, ST_x : 45,587 psi
 Tensile Modulus, E_x : 1,995,342 psi
 Ultimate Strain, ϵ_x : 0.0228 in/in
 Poisson's Ratio, v_{xy} : 0.1837

Measured Specimen Dimensions:

Width, W: 0.4746 in
 Thickness, H: 1.3588 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 5,880 lbs
 50% Max Load: 14,699 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

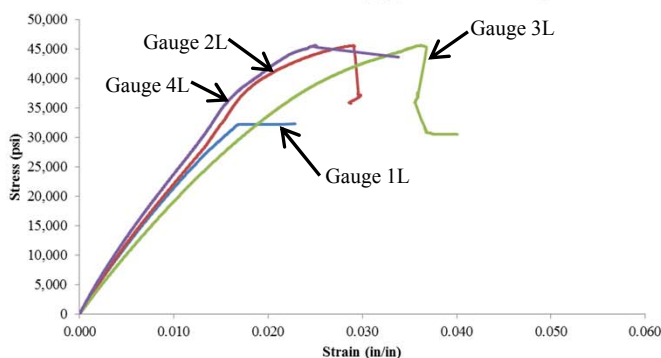


PICTURE OF SPECIMEN POST-TEST

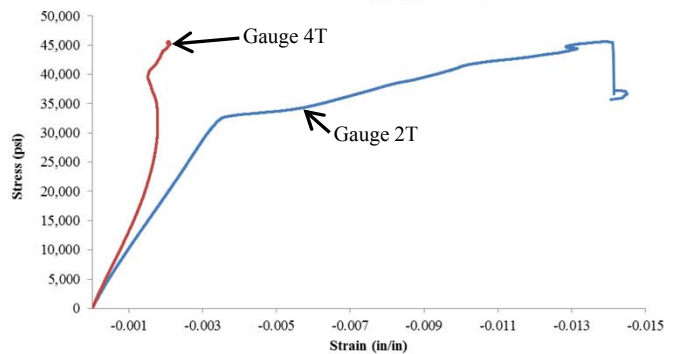


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0108 | 0.0038 | 1,962,646 | | | | |
| 2L | 0.0104 | 0.0037 | 2,051,979 | 2T | -0.0024 | -0.0009 | 0.2250 |
| 3L | 0.0122 | 0.0045 | 1,753,718 | 3T | -0.0034 | -0.0013 | 0.2679 |
| 4L | 0.0095 | 0.0033 | 2,213,025 | 4T | -0.0016 | -0.0007 | 0.1424 |
| Average | | | 1,995,342 | | | | 0.1837 |

Stress-Strain Curve 70_4_(08-02), Long.



Stress-Strain Curve 70_4_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-70-FY08**
 Test Date: 10/20/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 29,253 lbs
 Tensile Strength, ST_x : 46,177 psi
 Tensile Modulus, E_x : 2,149,310 psi
 Ultimate Strain, ϵ_x : 0.0215 in/in
 Poisson's Ratio, v_{xy} : 0.2735

Measured Specimen Dimensions:

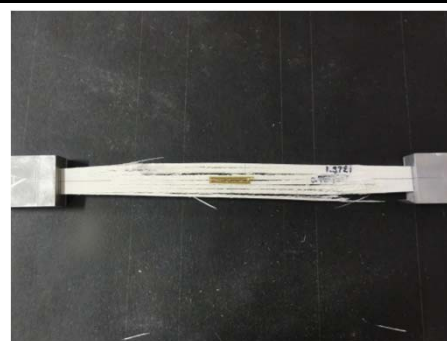
Width, W: 0.4617 in
 Thickness, H: 1.3721 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 5,851 lbs
 50% Max Load: 14,627 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

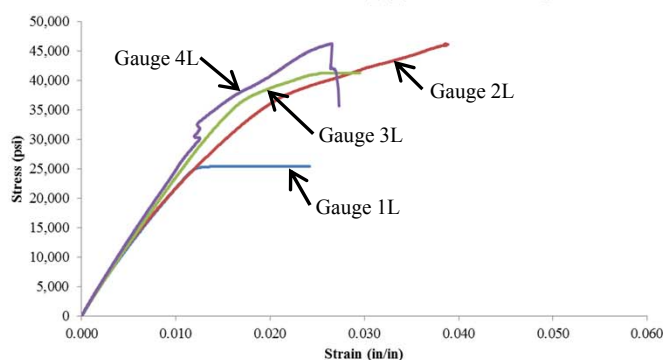


PICTURE OF SPECIMEN POST-TEST

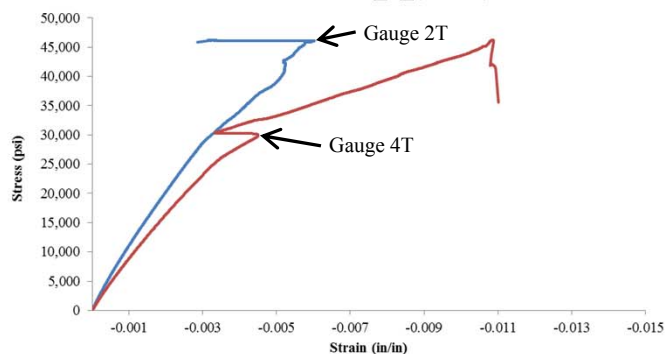


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0107 | 0.0038 | 1,992,737 | | | | |
| 2L | 0.0108 | 0.0037 | 1,936,076 | 2T | -0.0023 | -0.0008 | 0.2112 |
| 3L | 0.0098 | 0.0037 | 2,278,519 | 3T | -0.0027 | -0.0011 | 0.2634 |
| 4L | 0.0093 | 0.0035 | 2,389,910 | 4T | -0.0030 | -0.0010 | 0.3358 |
| Average | | | 2,149,310 | | | | 0.2735 |

Stress-Strain Curve 70_5_(08-02), Long.



Stress-Strain Curve 70_5_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

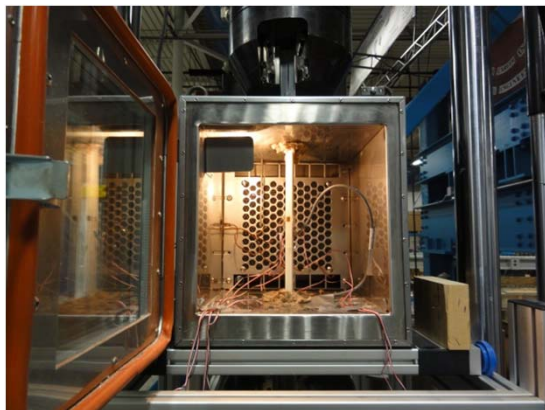
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-TX-140-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **ST_x, E_x, v_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **23,154** **lbs**
 Tensile Strength, ST_x: **31,910** **psi**
 Tensile Modulus, E_x: **1,656,583** **psi**
 Ultimate Strain, ε_x: **0.0198** **in/in**
 Poisson's Ratio, v_{xy}: **0.1765**

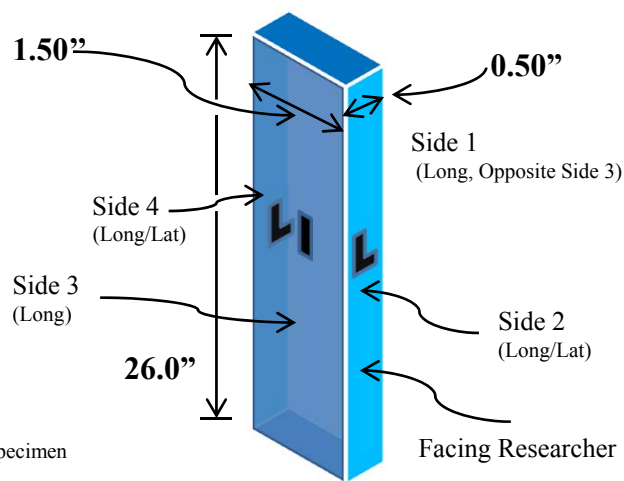
| Sample | Specimen | Ultimate Load, P _x (lbs) | Tensile Strength, ST _x (psi) | Tensile Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, v _{xy} | Failure Mode |
|----------------|--------------------|--|---|--|--|----------------------------------|--------------|
| 1 | MAT2-TX-1-140-FY08 | 22,380 | 31,299 | 1,560,459 | 0.0201 | 0.1840 | DGM |
| 2 | MAT2-TX-2-140-FY08 | 24,218 | 31,437 | 1,821,175 | 0.0173 | 0.0844 | DGM |
| 3 | MAT2-TX-3-140-FY08 | 22,630 | 31,476 | 1,236,603 | 0.0255 | 0.1882 | DGM |
| 4 | MAT2-TX-4-140-FY08 | 22,620 | 31,926 | 1,623,470 | 0.0197 | 0.2361 | DGM |
| 5 | MAT2-TX-5-140-FY08 | 23,921 | 33,411 | 2,041,208 | 0.0164 | 0.1899 | DGM |
| Average | | 23,154 | 31,910 | 1,656,583 | 0.0198 | 0.1765 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

140°F Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See C-14 to C-18 6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-30% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-140-FY08**
 Test Date: 10/27/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 22,380 lbs
 Tensile Strength, ST_x : 31,299 psi
 Tensile Modulus, E_x : 1,560,459 psi
 Ultimate Strain, ϵ_x : 0.0201 in/in
 Poisson's Ratio, v_{xy} : 0.1840

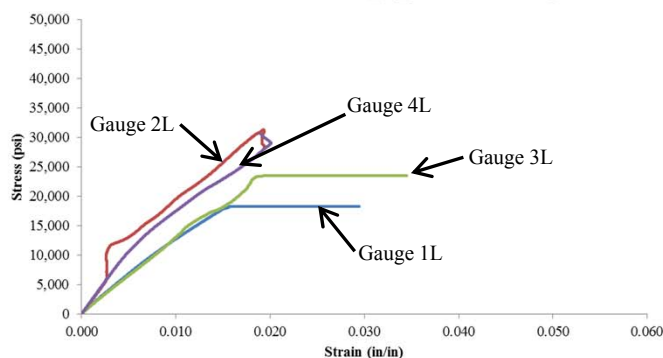
Measured Specimen Dimensions:

Width, W: 0.5021 in
 Thickness, H: 1.4241 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 2,238 lbs
 30% Max Load: 6,714 lbs

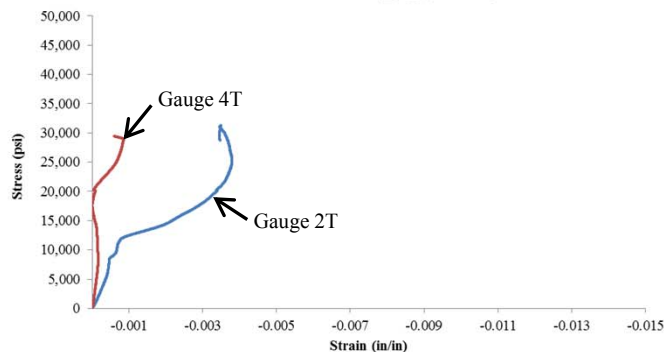
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0070 | 0.0022 | 1,289,678 | | | | |
| 2L | 0.0026 | 0.0015 | 5,522,467 | 2T | -0.0006 | -0.0002 | 0.3401 |
| 3L | 0.0073 | 0.0023 | 1,252,642 | | | | |
| 4L | 0.0043 | 0.0014 | 2,139,056 | 4T | -0.0002 | -0.0001 | 0.0279 |
| Average | | | 1,560,459 | | | | 0.1840 |

Stress-Strain Curve 140_1_(08-02), Long.



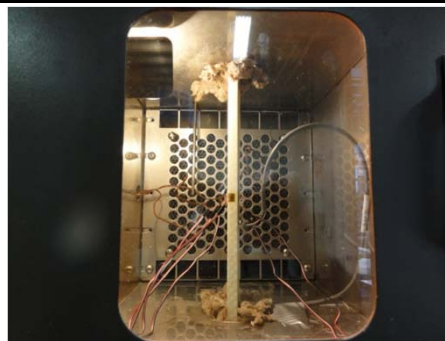
Stress-Strain Curve 140_1_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *The averaged tensile modulus reported for this test does not include gauge 2L due to its nonlinear behavior through the 10 – 30% range

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-140-FY08**
 Test Date: 10/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

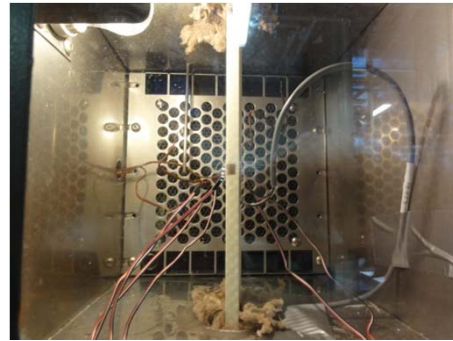
Ultimate Load, P_x : 24,218 lbs
 Tensile Strength, ST_x : 31,437 psi
 Tensile Modulus, E_x : 1,821,175 psi
 Ultimate Strain, ϵ_x : 0.0173 in/in
 Poisson's Ratio, v_{xy} : 0.0844

Measured Specimen Dimensions:

Width, W: 0.5489 in
 Thickness, H: 1.4035 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 2,422 lbs
 30% Max Load: 7,265 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

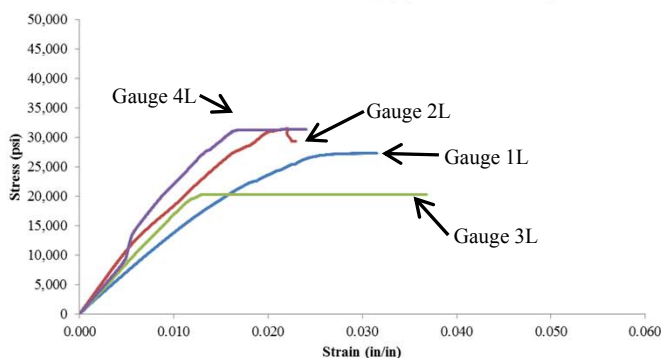


PICTURE OF SPECIMEN POST-TEST

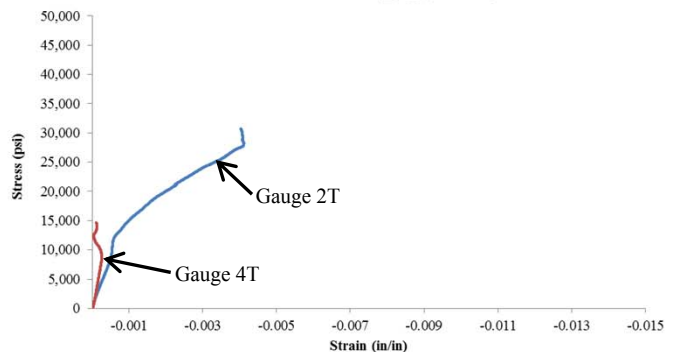


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0066 | 0.0021 | 1,390,043 | | | | |
| 2L | 0.0043 | 0.0014 | 2,176,859 | 2T | -0.0005 | -0.0002 | 0.1260 |
| 3L | 0.0055 | 0.0019 | 1,748,967 | | | | |
| 4L | 0.0049 | 0.0017 | 1,968,832 | 4T | -0.0003 | -0.0001 | 0.0428 |
| Average | | | 1,821,175 | | | | 0.0844 |

Stress-Strain Curve 140_2_(08-02), Long.



Stress-Strain Curve 140_2_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-140-FY08**
 Test Date: 10/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 22,630 lbs
 Tensile Strength, ST_x : 31,476 psi
 Tensile Modulus, E_x : 1,236,603 psi
 Ultimate Strain, ϵ_x : 0.0255 in/in
 Poisson's Ratio, v_{xy} : 0.1882

Measured Specimen Dimensions:

Width, W: 0.5131 in
 Thickness, H: 1.4012 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 2,263 lbs
 30% Max Load: 6,789 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

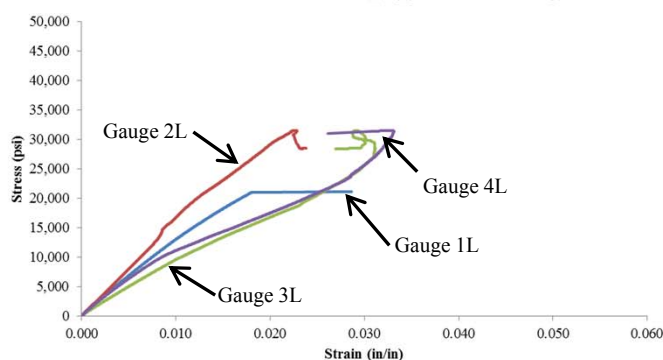


PICTURE OF SPECIMEN POST-TEST

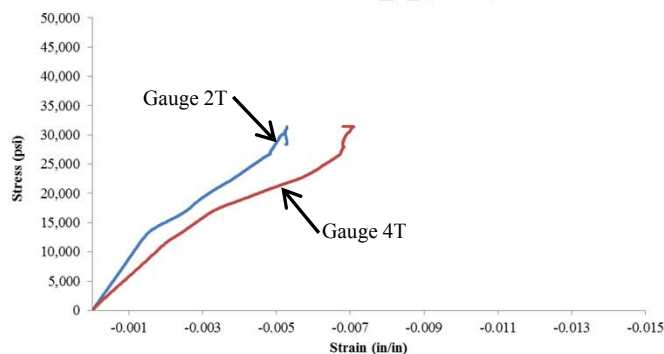


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0070 | 0.0022 | 1,296,005 | | | | |
| 2L | 0.0059 | 0.0020 | 1,596,277 | 2T | -0.0011 | -0.0004 | 0.1780 |
| 3L | 0.0098 | 0.0031 | 928,595 | | | | |
| 4L | 0.0079 | 0.0023 | 1,125,533 | 4T | -0.0016 | -0.0005 | 0.1983 |
| Average | | | 1,236,603 | | | | 0.1882 |

Stress-Strain Curve 140_3_(08-02), Long.



Stress-Strain Curve 140_3_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-140-FY08**
 Test Date: 11/1/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 22,620 lbs
 Tensile Strength, ST_x : 31,926 psi
 Tensile Modulus, E_x : 1,623,470 psi
 Ultimate Strain, ϵ_x : 0.0197 in/in
 Poisson's Ratio, v_{xy} : 0.2361

Measured Specimen Dimensions:

Width, W: 0.5016 in
 Thickness, H: 1.4125 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 2,262 lbs
 30% Max Load: 6,786 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

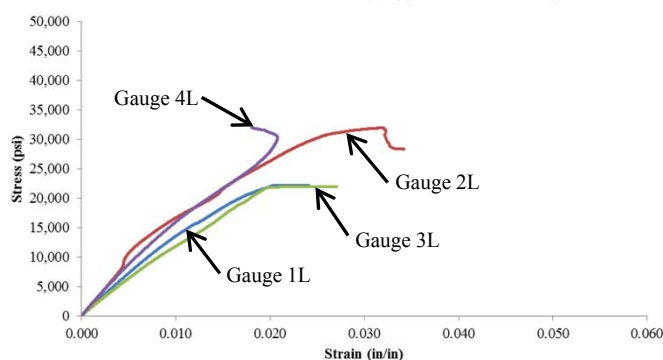


PICTURE OF SPECIMEN POST-TEST

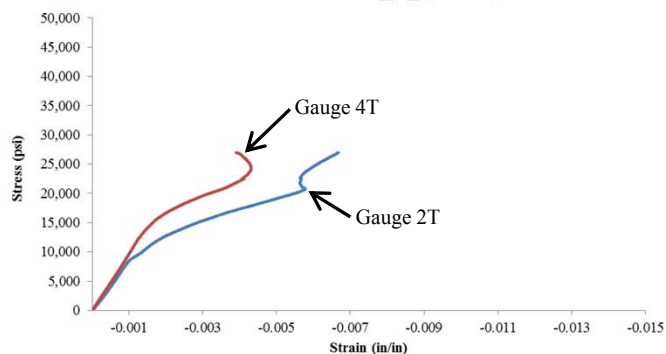


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0067 | 0.0021 | 1,386,624 | | | | |
| 2L | 0.0046 | 0.0017 | 2,241,768 | 2T | -0.0013 | -0.0004 | 0.3000 |
| 3L | 0.0077 | 0.0024 | 1,195,609 | | | | |
| 4L | 0.0055 | 0.0017 | 1,669,877 | 4T | -0.0010 | -0.0003 | 0.1723 |
| Average | | | 1,623,470 | | | | 0.2361 |

Stress-Strain Curve 140_4_(08-02), Long.



Stress-Strain Curve 140_4_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-140-FY08**
 Test Date: 11/1/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

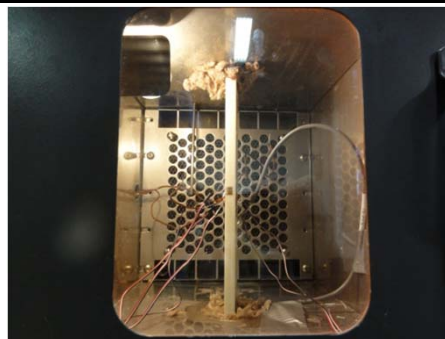
Ultimate Load, P_x : 23,921 lbs
 Tensile Strength, ST_x : 33,411 psi
 Tensile Modulus, E_x : 2,041,208 psi
 Ultimate Strain, ϵ_x : 0.0164 in/in
 Poisson's Ratio, v_{xy} : 0.1899

Measured Specimen Dimensions:

Width, W: 0.5037 in
 Thickness, H: 1.4214 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 2,392 lbs
 30% Max Load: 7,176 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

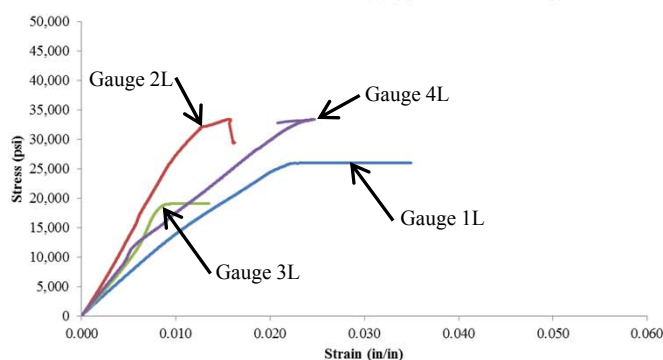


PICTURE OF SPECIMEN POST-TEST

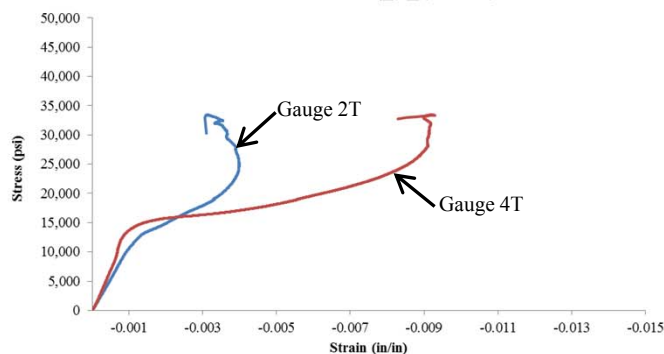


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0070 | 0.0022 | 1,406,185 | | | | |
| 2L | 0.0039 | 0.0014 | 2,706,828 | 2T | -0.0009 | -0.0003 | 0.2462 |
| 3L | 0.0053 | 0.0019 | 1,947,369 | | | | |
| 4L | 0.0049 | 0.0017 | 2,104,451 | 4T | -0.0007 | -0.0003 | 0.1336 |
| Average | | | 2,041,208 | | | | 0.1899 |

Stress-Strain Curve 140_5_(08-02), Long.



Stress-Strain Curve 140_5_(08-02), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-N40-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 52,555 lbs
 Compressive Strength, SC_x : 37,486 psi
 Compressive Modulus, E_x : 2,692,235 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.290

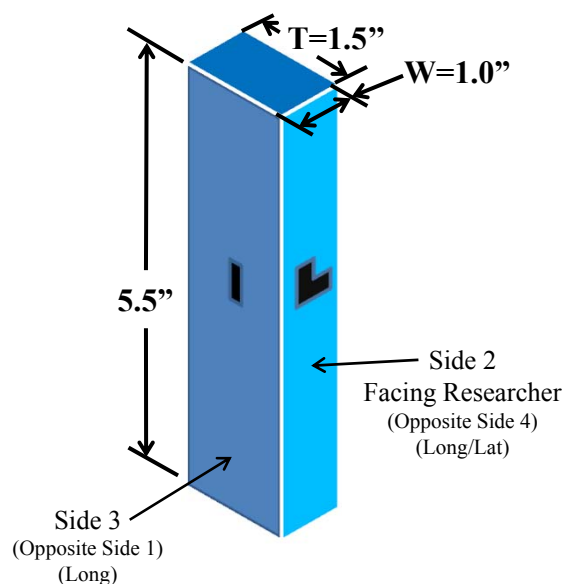
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT2-CX-01-N40-FY08 | 51,724 | 36,604 | 2,526,951 | 0.015 | 0.241 | Delamination |
| MAT2-CX-02-N40-FY08 | 49,230 | 36,542 | 2,805,322 | 0.013 | 0.289 | Delamination |
| MAT2-CX-03-N40-FY08 | 58,050 | 41,607 | 2,541,061 | 0.016 | 0.276 | Delamination |
| MAT2-CX-04-N40-FY08 | 53,207 | 37,286 | 2,708,618 | 0.014 | 0.332 | Delamination |
| MAT2-CX-05-N40-FY08 | 50,564 | 35,391 | 2,879,223 | 0.012 | 0.314 | Delamination |
| Average | 52,555 | 37,486 | 2,692,235 | 0.014 | 0.290 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown.
- 2) See C-20 to C-24 for individual specimen results.
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-01-N40-FY08**
 Test Date: 6/27/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 51,724 lbs
 Compressive Strength, SC_x : 36,604 psi
 Compressive Modulus, E_x : 2,526,951 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.241

Measured Specimen Dimensions:

Width, W: 1.0130 in
 Thickness, H: 1.3950 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 10,345 lbs
 50% Max Load: 25,862 lbs

PICTURE OF SPECIMEN PRE-TEST



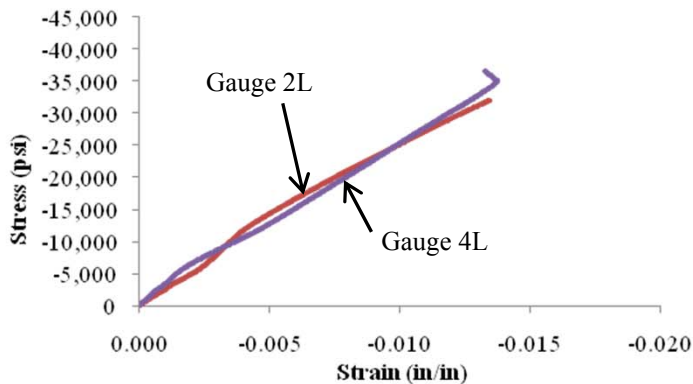
PICTURE OF SPECIMEN POST-TEST



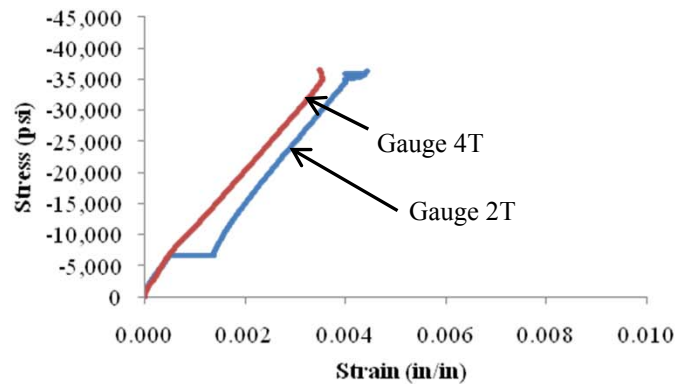
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.00671 | -0.00278 | 2,799,952 | 2T | 0.00226 | 0.00137 | 0.227 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.00721 | -0.00234 | 2,253,951 | 4T | 0.00177 | 0.00054 | 0.254 |
| Average | | | 2,526,951 | | | | 0.241 |

Stress-Strain Curve N40_01_(08-02)_Long



Stress-Strain Curve N40_01_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Longitudinal gauges 1L and 3L were lost

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-02-N40-FY08
 Test Date: 9/8/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 49,230 lbs
 Compressive Strength, SC_x : 36,542 psi
 Compressive Modulus, E_x : 2,805,322 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.289

Measured Specimen Dimensions:

Width, W: 1.0015 in
 Thickness, H: 1.3452 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 9,846 lbs
 50% Max Load: 24,615 lbs

PICTURE OF SPECIMEN PRE-TEST



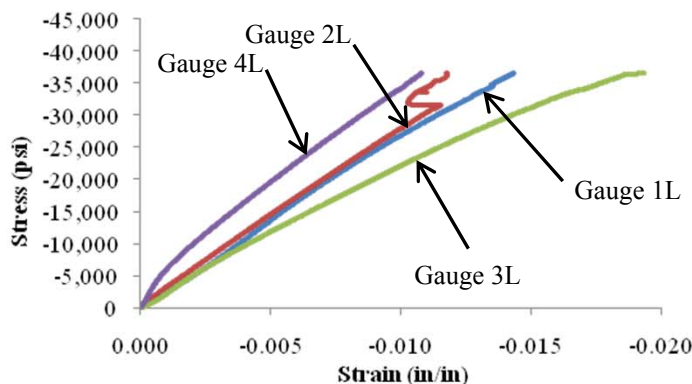
PICTURE OF SPECIMEN POST-TEST



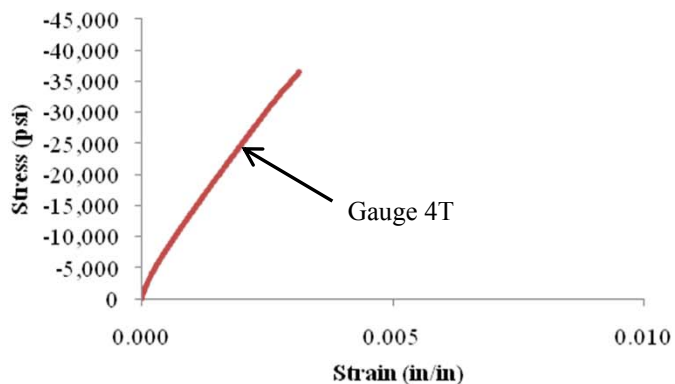
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00659 | -0.00285 | 2,929,614 | | | | |
| 2L | -0.00634 | -0.00242 | 2,793,983 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00807 | -0.00295 | 2,139,314 | | | | |
| 4L | -0.00456 | -0.00130 | 3,358,377 | 4T | 0.00138 | 0.00043 | 0.289 |
| Average | | | 2,805,322 | | | | 0.289 |

Stress-Strain Curve N40_02_(08-02)_Long



Stress-Strain Curve N40_02_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-03-N40-FY08
 Test Date: 6/28/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 58,050 lbs
 Compressive Strength, SC_x : 41,607 psi
 Compressive Modulus, E_x : 2,541,061 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson's Ratio, ν_{xy} : 0.276

Measured Specimen Dimensions:

Width, W: 0.9980 in
 Thickness, H: 1.3980 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 11,610 lbs
 50% Max Load: 29,025 lbs

PICTURE OF SPECIMEN PRE-TEST



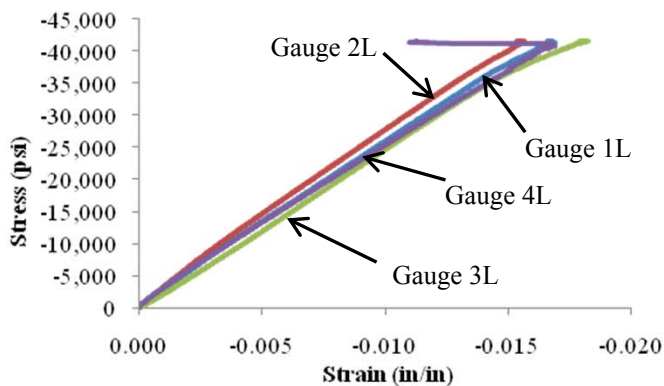
PICTURE OF SPECIMEN POST-TEST



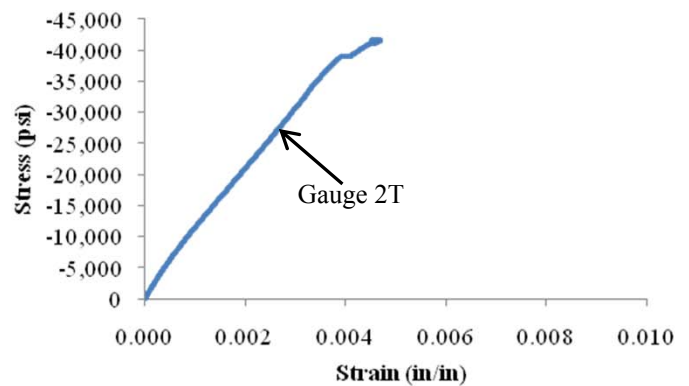
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00793 | -0.00297 | 2,515,162 | | | | |
| 2L | -0.00732 | -0.00267 | 2,679,962 | 2T | 0.00197 | 0.00069 | 0.276 |
| 3L | -0.00848 | -0.00354 | 2,528,117 | | | | |
| 4L | -0.00808 | -0.00296 | 2,441,003 | 4T | Lost Gauge | Lost Gauge | - |
| Average | | | 2,541,061 | | | | 0.276 |

Stress-Strain Curve N40_03_(08-02)_Long



Stress-Strain Curve N40_03_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Lateral gauge 4T was lost

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-04-N40-FY08
 Test Date: 6/28/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 53,207 lbs
 Compressive Strength, SC_x : 37,286 psi
 Compressive Modulus, E_x : 2,708,618 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, v_{xy} : 0.332

Measured Specimen Dimensions:

Width, W: 1.000 in
 Thickness, H: 1.4270 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 10,641 lbs
 50% Max Load: 26,603 lbs

PICTURE OF SPECIMEN PRE-TEST



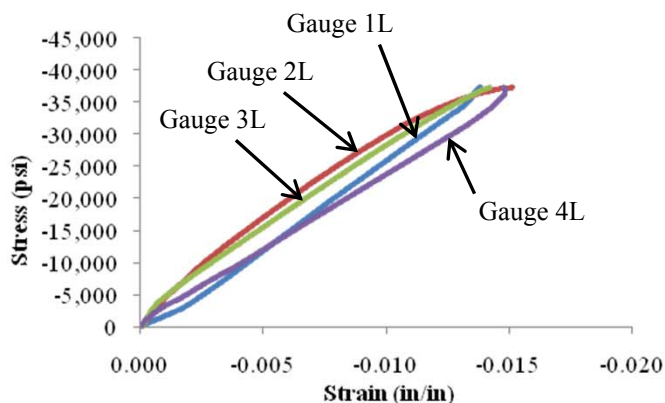
PICTURE OF SPECIMEN POST-TEST



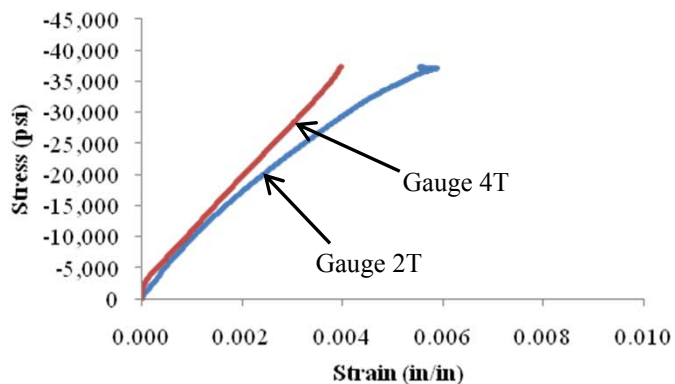
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00737 | -0.00347 | 2,866,748 | | | | |
| 2L | -0.00557 | -0.00187 | 3,025,934 | 2T | 0.00220 | 0.00073 | 0.398 |
| 3L | -0.00619 | -0.00194 | 2,633,779 | | | | |
| 4L | -0.00779 | -0.00294 | 2,308,012 | 4T | 0.00187 | 0.00058 | 0.266 |
| Average | | | 2,708,748 | | | | 0.332 |

Stress-Strain Curve N40_04_(08-02)_Long



Stress-Strain Curve N40_04_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-05-N40-FY08
 Test Date: 6/28/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

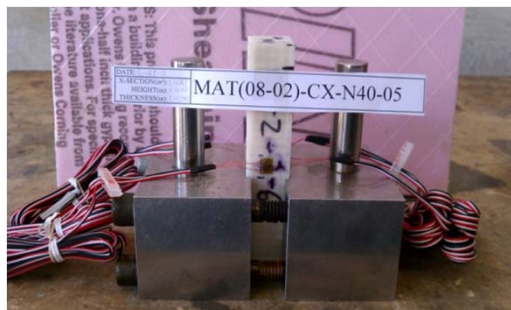
Average Material Properties:

Maximum Load, P_x : 50,564 lbs
 Compressive Strength, SC_x : 35,391 psi
 Compressive Modulus, E_x : 2,879,223 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.314

Measured Specimen Dimensions:

Width, W: 1.0140 in
 Thickness, H: 1.4090 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 10,113 lbs
 50% Max Load: 25,282 lbs

PICTURE OF SPECIMEN PRE-TEST



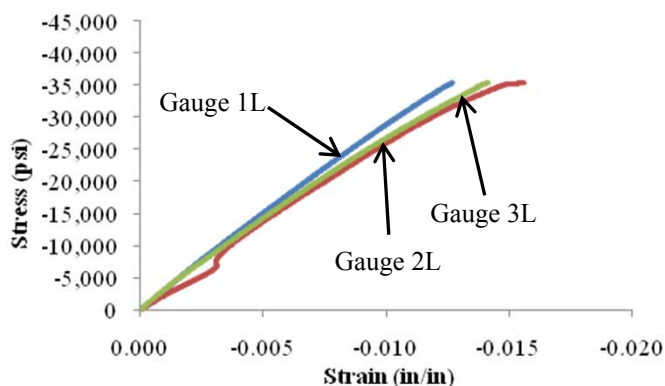
PICTURE OF SPECIMEN POST-TEST



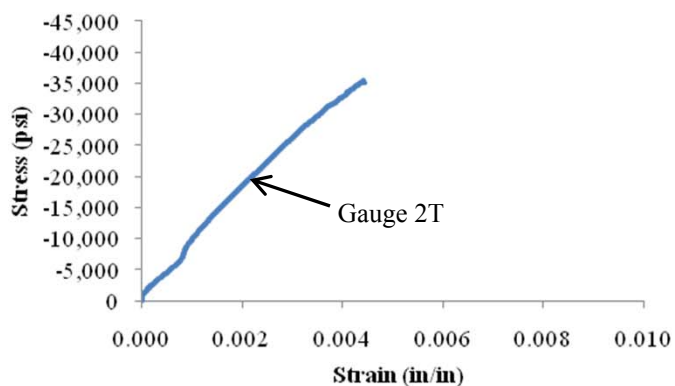
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00592 | -0.0021 | 2,890,667 | | | | |
| 2L | -0.00658 | -0.0023 | 3,063,380 | 2T | 0.00190 | 0.00083 | 0.314 |
| 3L | -0.00630 | -0.0024 | 2,683,622 | | | | |
| 4L | Lost Gauge | Lost Gauge | - | 4T | Lost Gauge | Lost Gauge | - |
| Average | | | 2,879,223 | | | | 0.314 |

Stress-Strain Curve N40_05_(08-02)_Long



Stress-Strain Curve N40_05_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Longitudinal and lateral strain gauges on side four were lost

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

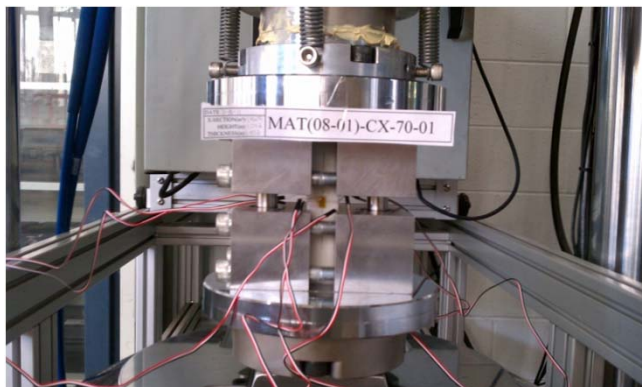
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-70-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 35,508 lbs
 Compressive Strength, SC_x : 25,009 psi
 Compressive Modulus, E_x : 2,717,877 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.297

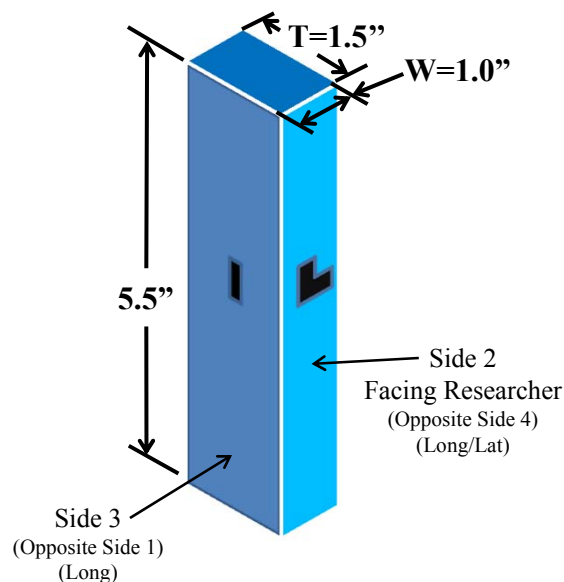
| Specimen | MaxLoad, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT2-CX-01-70-FY08 | 35,487 | 24,994 | 2,708,351 | 0.009 | 0.348 | Delamination |
| MAT2-CX-02-70-FY08 | 38,449 | 26,929 | 2,556,539 | 0.011 | 0.269 | Delamination |
| MAT2-CX-03-70-FY08 | 32,035 | 22,743 | 2,832,976 | 0.008 | 0.329 | Delamination |
| MAT2-CX-04-70-FY08 | 37,822 | 26,355 | 2,740,295 | 0.010 | 0.208 | Delamination |
| MAT2-CX-05-70-FY08 | 33,749 | 24,022 | 2,751,224 | 0.010 | 0.331 | Delamination |
| Average | 35,508 | 25,009 | 2,717,877 | 0.010 | 0.297 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See C-26 to C-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-01-70-FY08**
 Test Date: 7/14/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

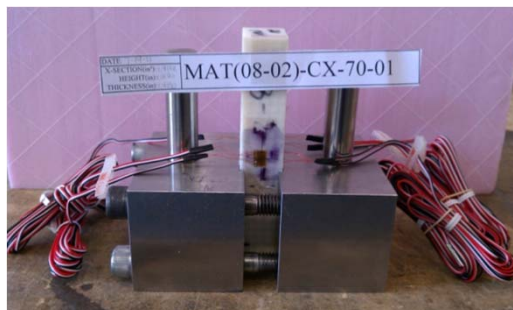
Average Material Properties:

Maximum Load, P_x : 35,487 lbs
 Compressive Strength, SC_x : 24,994 psi
 Compressive Modulus, E_x : 2,708,351 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, v_{xy} : 0.348

Measured Specimen Dimensions:

Width, W: 1.0120 in
 Thickness, H: 1.4030 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,097 lbs
 50% Max Load: 17,743 lbs

PICTURE OF SPECIMEN PRE-TEST



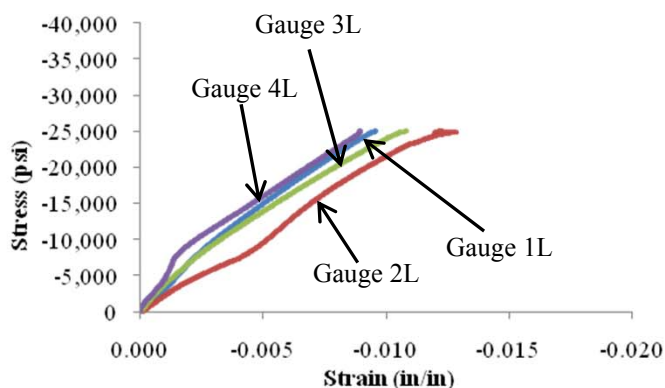
PICTURE OF SPECIMEN POST-TEST



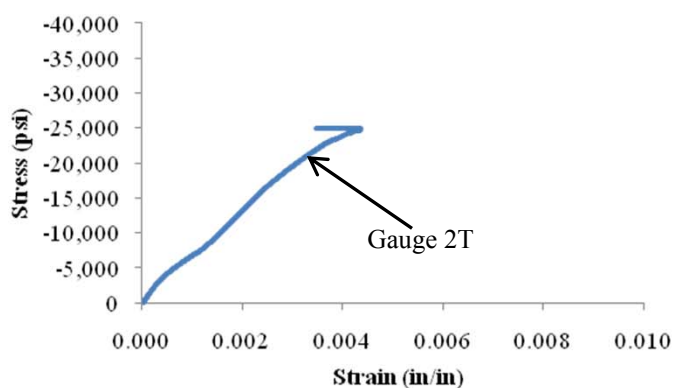
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00400 | -0.00150 | 3,004,231 | | | | |
| 2L | -0.00601 | -0.00241 | 2,081,601 | 2T | 0.00190 | 0.00065 | 0.348 |
| 3L | -0.00435 | -0.00139 | 2,527,749 | | | | |
| 4L | -0.00339 | -0.00106 | 3,219,824 | 4T | Lost Gauge | Lost Gauge | - |
| Average | | | 2,708,351 | | | | 0.348 |

Stress-Strain Curve 70F_01_(08-02)_Long



Stress-Strain Curve 70F_01_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-02-70-FY08**
 Test Date: 7/14/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 38,449 lbs
 Compressive Strength, SC_x : 26,929 psi
 Compressive Modulus, E_x : 2,556,539 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, v_{xy} : 0.269

Measured Specimen Dimensions:

Width, W: 0.9950 in
 Thickness, H: 1.4350 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,690 lbs
 50% Max Load: 19,224 lbs

PICTURE OF SPECIMEN PRE-TEST



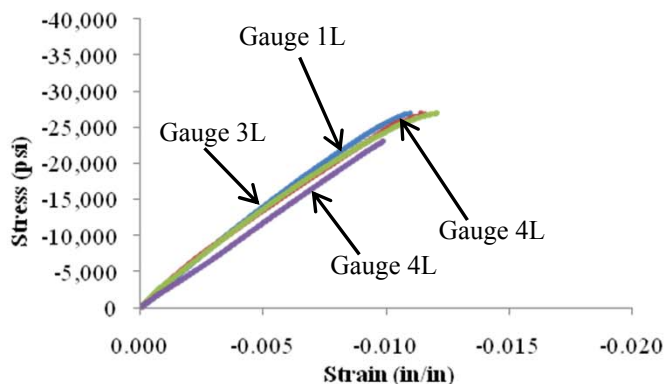
PICTURE OF SPECIMEN POST-TEST



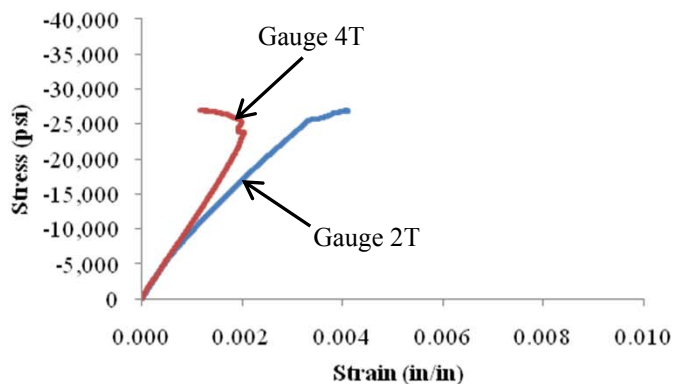
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00478 | -0.00184 | 2,741,862 | | | | |
| 2L | -0.00498 | -0.00173 | 2,481,752 | 2T | 0.00150 | 0.00049 | 0.312 |
| 3L | -0.00491 | -0.00180 | 2,594,691 | | | | |
| 4L | -0.00570 | -0.00234 | 2,407,850 | 4T | 0.00123 | 0.00047 | 0.227 |
| Average | | | 2,556,539 | | | | 0.269 |

Stress-Strain Curve 70F_02_(08-02)_Long



Stress-Strain Curve 70F_02_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-03-70-FY08**
 Test Date: 7/14/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 32,035 lbs
 Compressive Strength, SC_x : 22,743 psi
 Compressive Modulus, E_x : 2,832,976 psi
 Ultimate Strain, ϵ_x : 0.008 in/in
 Poisson's Ratio, ν_{xy} : 0.329

Measured Specimen Dimensions:

Width, W: 0.9990 in
 Thickness, H: 1.4100 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,407 lbs
 50% Max Load: 16,018 lbs

PICTURE OF SPECIMEN PRE-TEST



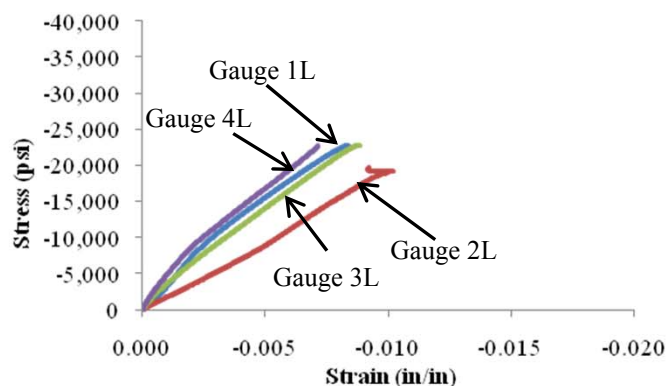
PICTURE OF SPECIMEN POST-TEST



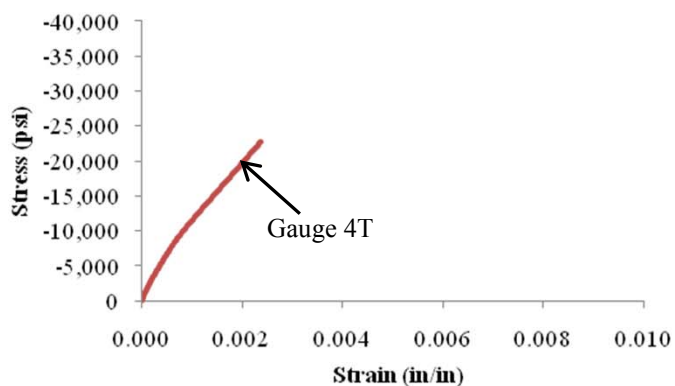
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00334 | -0.00132 | 3,392,912 | | | | |
| 2L | -0.00610 | -0.00262 | 1,960,310 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00393 | -0.00131 | 2,610,114 | | | | |
| 4L | -0.00294 | -0.00092 | 3,368,569 | 4T | 0.00098 | 0.00031 | 0.329 |
| Average | | | 2,832,976 | | | | 0.329 |

Stress-Strain Curve 70F_03_(08-02)_Long



Stress-Strain Curve 70F_03_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-04-70-FY08**
 Test Date: 7/14/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 37,822 lbs
 Compressive Strength, SC_x : 26,355 psi
 Compressive Modulus, E_x : 2,740,295 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : 0.208

Measured Specimen Dimensions:

Width, W: 1.0200 in
 Thickness, H: 1.4070 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,564 lbs
 50% Max Load: 18,911 lbs

PICTURE OF SPECIMEN PRE-TEST



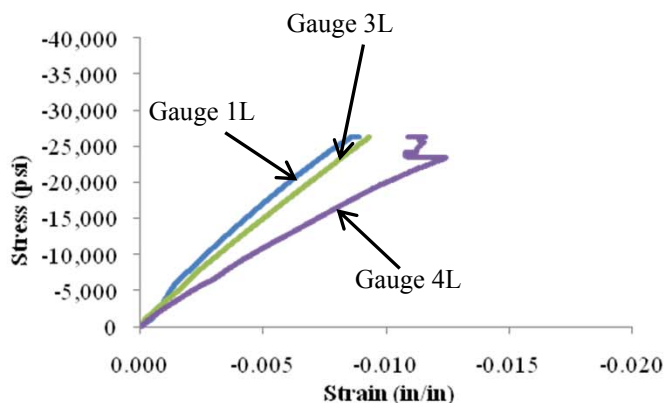
PICTURE OF SPECIMEN POST-TEST



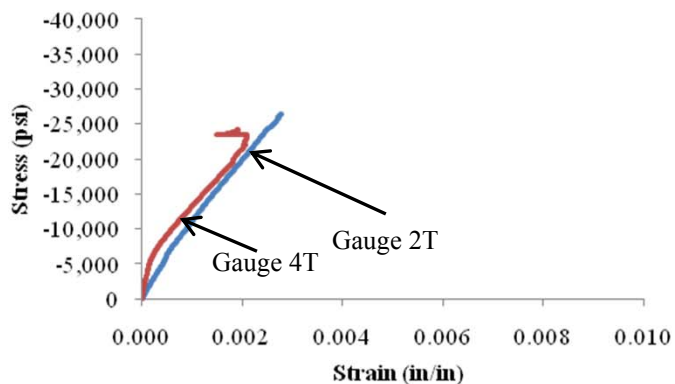
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00367 | -0.00127 | 3,292,372 | | | | |
| 2L | Lost Gauge | Lost Gauge | - | 2T | 0.00044 | 0.00044 | N/A |
| 3L | -0.00432 | -0.00163 | 2,942,877 | | | | |
| 4L | -0.00622 | -0.00224 | 1,985,636 | 4T | 0.00099 | 0.00016 | 0.208 |
| Average | | | 2,740,295 | | | | 0.208 |

Stress-Strain Curve 70F_04_(08-02)_Long



Stress-Strain Curve 70F_04_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-05-70-FY08**
 Test Date: 7/14/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 33,749 lbs
 Compressive Strength, SC_x : 24,022 psi
 Compressive Modulus, E_x : 2,546,869 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.331

Measured Specimen Dimensions:

Width, W: 0.9790 in
 Thickness, H: 1.4350 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,750 lbs
 50% Max Load: 16,874 lbs

PICTURE OF SPECIMEN PRE-TEST



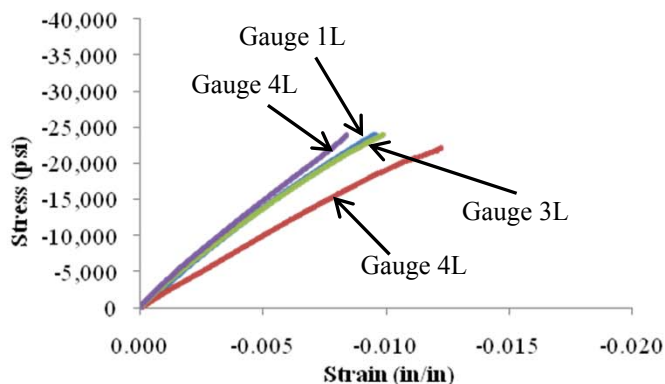
PICTURE OF SPECIMEN POST-TEST



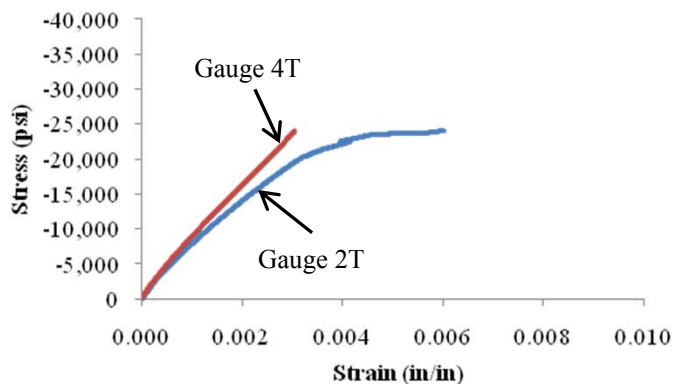
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00426 | -0.00164 | 2,751,224 | | | | |
| 2L | -0.00602 | -0.00238 | 1,980,661 | 2T | 0.00165 | 0.00055 | 0.301 |
| 3L | -0.00427 | -0.00152 | 2,623,852 | | | | |
| 4L | -0.00392 | -0.00138 | 2,831,738 | 4T | 0.00140 | 0.00048 | 0.362 |
| Average | | | 2,546,869 | | | | 0.331 |

Stress-Strain Curve 70F_05_(08-02)_Long



Stress-Strain Curve 70F_05_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-140-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 17,987 lbs
 Compressive Strength, SC_x : 12,826 psi
 Compressive Modulus, E_x : 2,340,062 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, ν_{xy} : 0.279

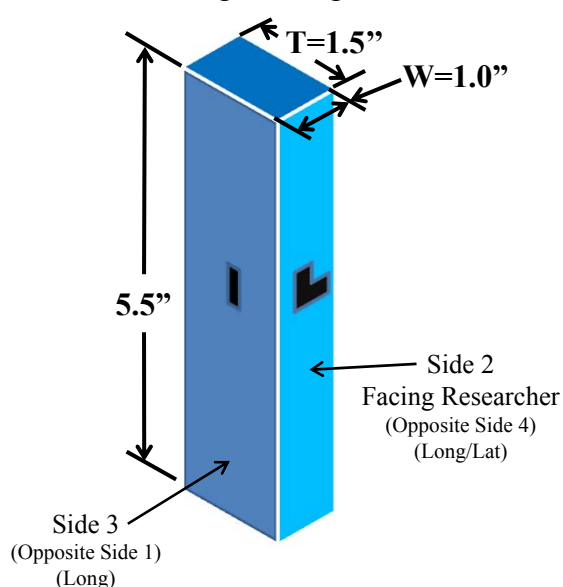
| Sample | Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT2-CX-01-140-FY08 | 17,814 | 12,618 | 2,147,915 | 0.007 | 0.279 | Delam |
| 2 | MAT2-CX-02-140-FY08 | 20,129 | 14,571 | 2,513,921 | 0.006 | 0.253 | Delam |
| 3 | MAT2-CX-03-140-FY08 | 13,963 | 10,273 | 2,573,209 | 0.004 | 0.532 | Delam |
| 4 | MAT2-CX-04-140-FY08 | 17,263 | 12,246 | 1,900,530 | 0.007 | 0.100 | Delam |
| 5 | MAT2-CX-05-140-FY08 | 20,765 | 14,420 | 2,564,733 | 0.006 | 0.232 | Delam |
| Average | | 17,987 | 12,826 | 2,340,062 | 0.006 | 0.279 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641 measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See C-32 to C-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-01-140-FY08
 Test Date: 7/8/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 17,814 lbs
 Compressive Strength, SC_x : 12,618 psi
 Compressive Modulus, E_x : 2,147,915 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, ν_{xy} : 0.279

Measured Specimen Dimensions:

Width, W: 0.9900 in
 Thickness, H: 1.4260 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,563 lbs
 50% Max Load: 8,907 lbs

PICTURE OF SPECIMEN PRE-TEST



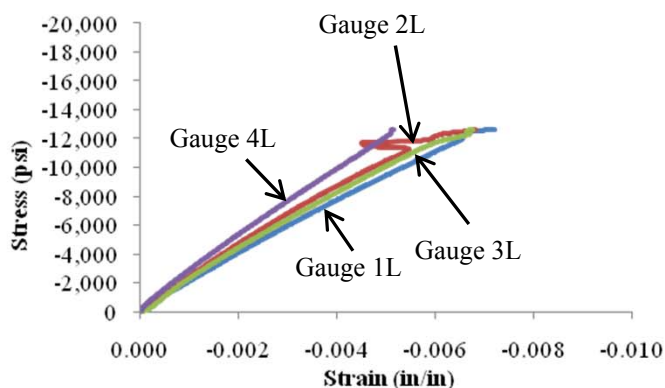
PICTURE OF SPECIMEN POST-TEST



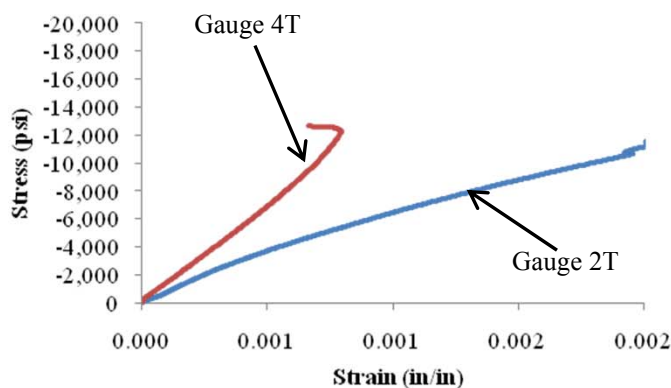
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00318 | -0.00120 | 1,904,894 | | | | |
| 2L | -0.00274 | -0.00102 | 2,200,585 | 2T | 0.00097 | 0.00032 | 0.379 |
| 3L | -0.00294 | -0.00109 | 2,043,092 | | | | |
| 4L | -0.00239 | -0.00084 | 2,443,088 | 4T | 0.00018 | 0.00046 | 0.180 |
| Average | | | 2,147,915 | | | | 0.279 |

Stress-Strain Curve 140F_01_(08-02)_Long



Stress-Strain Curve 140F_01_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-02-140-FY08**
 Test Date: 9/7/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 20,129 lbs
 Compressive Strength, SC_x : 14,571 psi
 Compressive Modulus, E_x : 2,513,921 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, ν_{xy} : 0.253

Measured Specimen Dimensions:

Width, W: 1.0083 in
 Thickness, H: 1.3701 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,026 lbs
 50% Max Load: 10,065 lbs

PICTURE OF SPECIMEN PRE-TEST



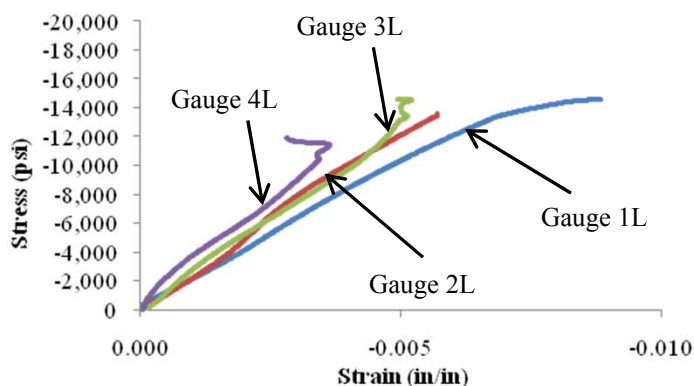
PICTURE OF SPECIMEN POST-TEST



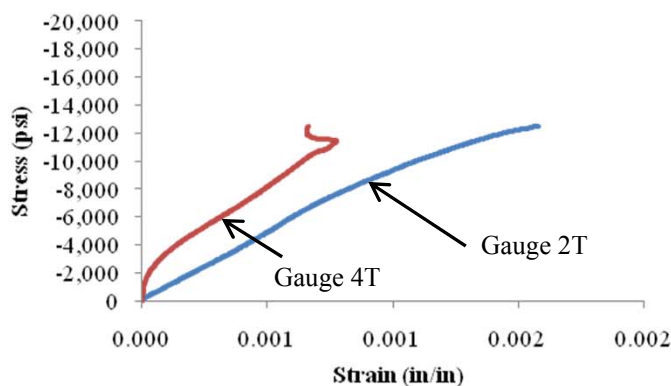
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00341 | -0.00140 | 2,169,831 | | | | |
| 2L | -0.00275 | -0.00130 | 3,023,043 | 2T | 0.00073 | 0.00030 | 0.300 |
| 3L | -0.00291 | -0.00104 | 2,343,079 | | | | |
| 4L | -0.00244 | -0.00070 | 2,519,730 | 4T | 0.00043 | 0.00007 | 0.207 |
| Average | | | 2,513,921 | | | | 0.253 |

Stress-Strain Curve 140F_02_(08-02)_Long



Stress-Strain Curve 140F_02_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-03-140-FY08
 Test Date: 9/7/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 13,963 lbs
 Compressive Strength, SC_x : 10,273 psi
 Compressive Modulus, E_x : 2,573,209 psi
 Ultimate Strain, ϵ_x : 0.004 in/in
 Poisson's Ratio, ν_{xy} : 0.532

Measured Specimen Dimensions:

Width, W: 1.0030 in
 Thickness, H: 1.3551 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,793 lbs
 50% Max Load: 6,982 lbs

PICTURE OF SPECIMEN PRE-TEST



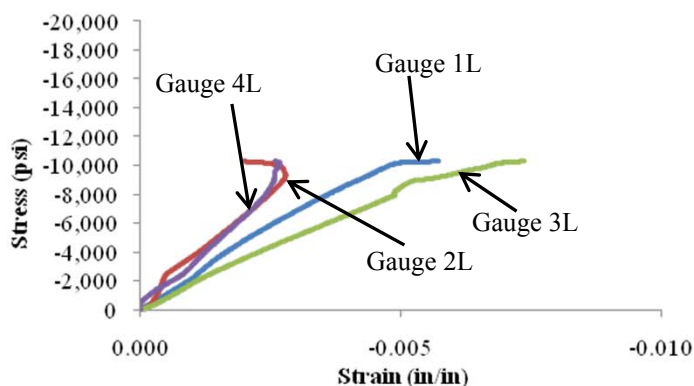
PICTURE OF SPECIMEN POST-TEST



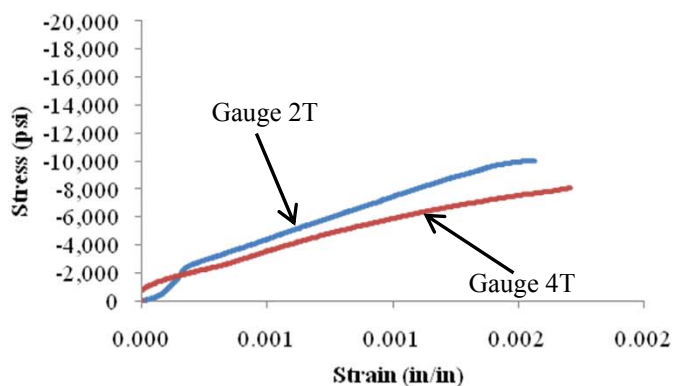
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00213 | -0.00094 | 2,578,425 | | | | |
| 2L | -0.00152 | -0.00044 | 2,851,435 | 2T | 0.00061 | 0.00016 | 0.419 |
| 3L | -0.00299 | -0.00110 | 1,631,350 | | | | |
| 4L | -0.00157 | -0.00062 | 3,231,626 | 4T | 0.00082 | 0.00020 | 0.644 |
| Average | | | 2,573,209 | | | | 0.532 |

Stress-Strain Curve 140F_03_(08-02)_Long



Stress-Strain Curve 140F_03_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-04-140-FY08**
 Test Date: 7/11/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 17,263 lbs
 Compressive Strength, SC_x : 12,246 psi
 Compressive Modulus, E_x : 1,900,530 psi
 Ultimate Strain, ϵ_x : 0.007 in/in
 Poisson's Ratio, ν_{xy} : 0.100

Measured Specimen Dimensions:

Width, W: 1.0110 in
 Thickness, H: 1.3944 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,453 lbs
 50% Max Load: 8,632 lbs

PICTURE OF SPECIMEN PRE-TEST



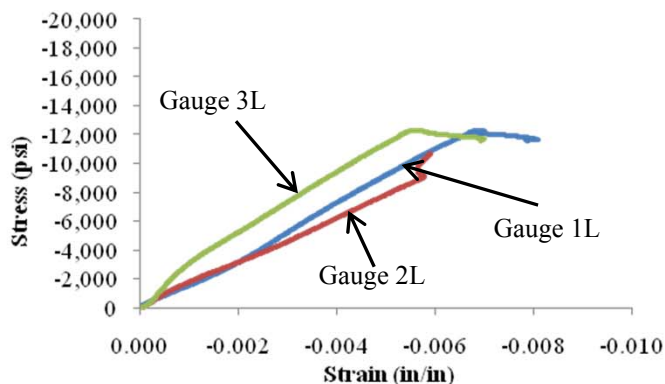
PICTURE OF SPECIMEN POST-TEST



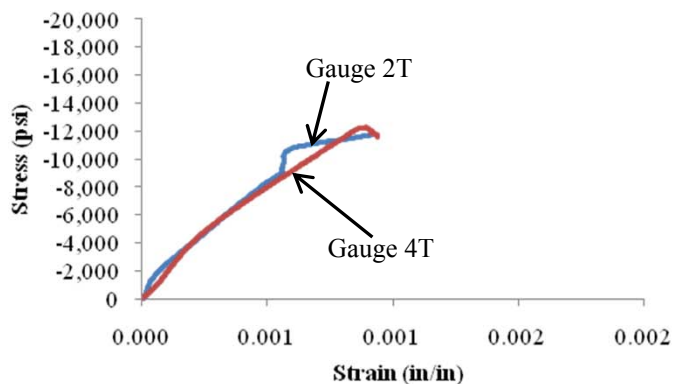
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00341 | -0.0029 | 2,010,407 | | | | |
| 2L | -0.00394 | -0.0018 | 1,478,414 | 2T | 0.00034 | 0.00009 | 0.100 |
| 3L | -0.00243 | -0.0019 | 2,212,768 | | | | |
| 4L | Lost Gauge | Lost Gauge | - | 4T | 0.00035 | 0.00012 | N/A |
| Average | | | 1,900,530 | | | | 0.100 |

Stress-Strain Curve 140F_04_(08-02)_Long



Stress-Strain Curve 140F_04_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-05-140-FY08**
 Test Date: 7/13/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 20,765 lbs
 Compressive Strength, SC_x : 14,420 psi
 Compressive Modulus, E_x : 2,564,733 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, v_{xy} : 0.232

Measured Specimen Dimensions:

Width, W: 1.0220 in
 Thickness, H: 1.4090 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,153 lbs
 50% Max Load: 10,382 lbs

PICTURE OF SPECIMEN PRE-TEST



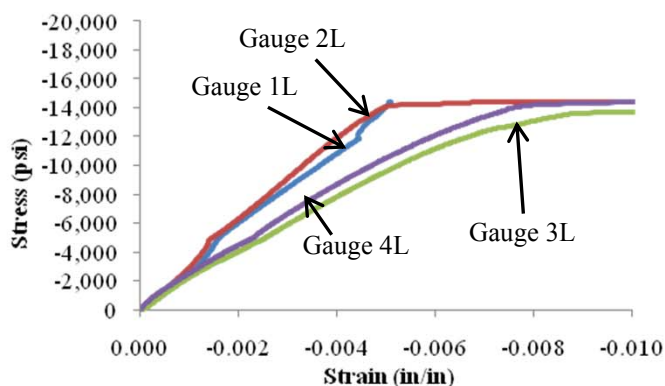
PICTURE OF SPECIMEN POST-TEST



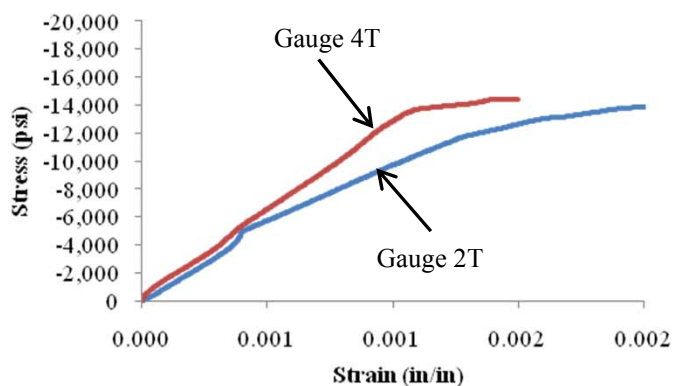
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|----------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00247 | -0.00111 | 3,162,613 | | | | |
| 2L | -0.00233 | -0.00098 | 3,196,574 | 2T | 0.00069 | 0.00028 | 0.303 |
| 3L | -0.00367 | -0.00132 | 1,843,226 | | | | |
| 4L | -0.00326 | -0.00116 | 2,056,518 | 4T | 0.00055 | 0.00022 | 0.161 |
| Average | | | 2,564,733 | | | | 0.232 |

Stress-Strain Curve 140F_05_(08-02)_Long



Stress-Strain Curve 140F_05_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

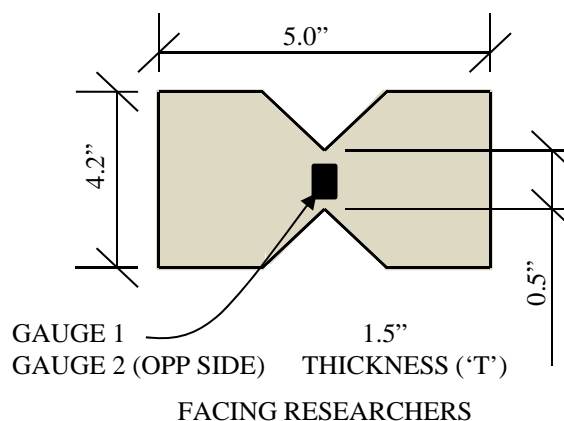
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-SXY-N40-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: G_{xy} , S_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : 19,936 lbs
 Shear Strength, S_{xy} : 23,690 psi
 Shear Modulus, G_{xy} : 1,241,458 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT2-SXY-01-N40-FY08 | 22,010 | 24,983 | 1,110,206 | Shear |
| 2 | MAT2-SXY-02-N40-FY08 | 20,858 | 24,890 | 1,427,021 | Shear |
| 3 | MAT2-SXY-03-N40-FY08 | 20,385 | 24,531 | 1,305,304 | Shear |
| 4 | MAT2-SXY-04-N40-FY08 | 20,193 | 24,417 | 1,129,652 | Shear |
| 5 | MAT2-SXY-05-N40-FY08 | 16,235 | 19,631 | 1,235,106 | Shear |
| Average | | 19,936 | 23,690 | 1,241,458 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-38 to C-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-N40-FY08
 Test Date: 8/2/11
 Specimen Received: 4/19/11
 Properties Measured: S_{xy} , G_{xy}

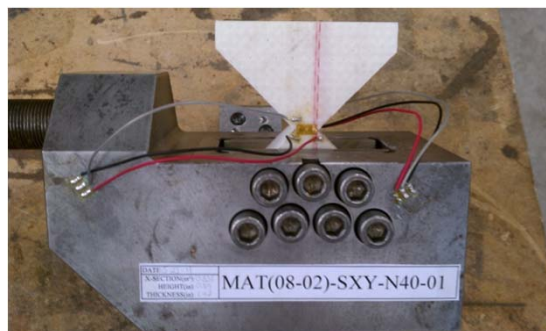
Average Material Properties:

Maximum Load, P_{max} : 22,010 lbs
 Shear Strength, S_{xy} : 24,983 psi
 Shear Modulus, G_{xy} : 1,110,206 psi

Measured Specimen Dimensions:

Thickness, T : 1.38 in
 Notch Length, N : 0.62 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,402 lbs
 50% Max Load: 11,005 lbs

PICTURE OF SPECIMEN PRE-TEST



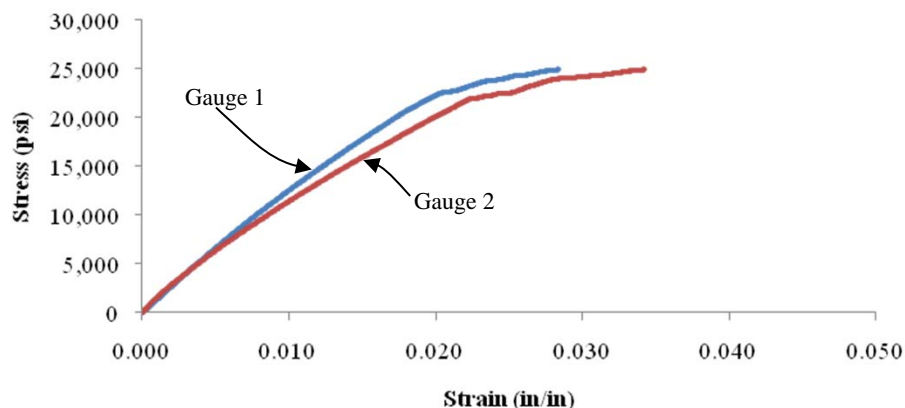
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00993 | 0.00368 | 1,199,551 |
| 2 | 0.01110 | 0.00375 | 1,020,862 |
| Average | | | 1,110,206 |

Stress-Strain Curve N40_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-N40-FY08
 Test Date: 5/24/11
 Specimen Received: 4/19/11
 Properties Measured: S_{xy} , G_{xy}

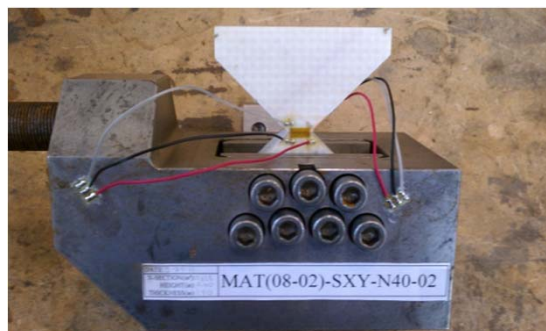
Average Material Properties:

Maximum Load, P_{max} : 20,858 lbs
 Shear Strength, S_{xy} : 24,890 psi
 Shear Modulus, G_{xy} : 1,427,012 psi

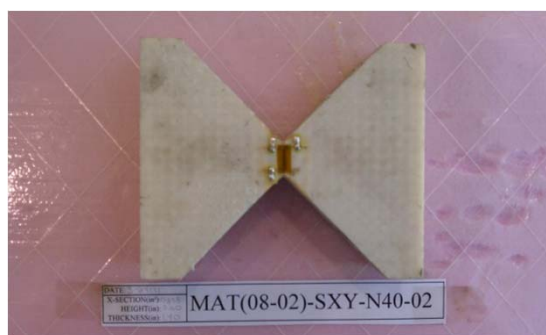
Measured Specimen Dimensions:

Thickness, T: 1.38 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,172 lbs
 50% Max Load: 10,429 lbs

PICTURE OF SPECIMEN PRE-TEST



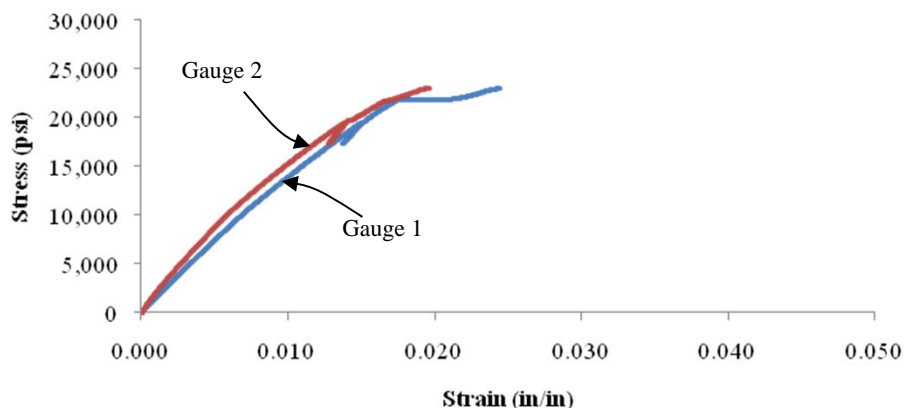
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00878 | 0.00330 | 1,361,299 |
| 2 | 0.00767 | 0.00267 | 1,492,724 |
| Average | | | 1,427,012 |

Stress-Strain Curve N40_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-N40-FY08
 Test Date: 5/31/11
 Specimen Received: 4/19/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 20,385 lbs
 Shear Strength, S_{xy} : 24,531 psi
 Shear Modulus, G_{xy} : 1,305,304 psi

Measured Specimen Dimensions:

Thickness, T: 1.41 in
 Notch Length, N: 0.59 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,077 lbs
 50% Max Load: 10,193 lbs

PICTURE OF SPECIMEN PRE-TEST



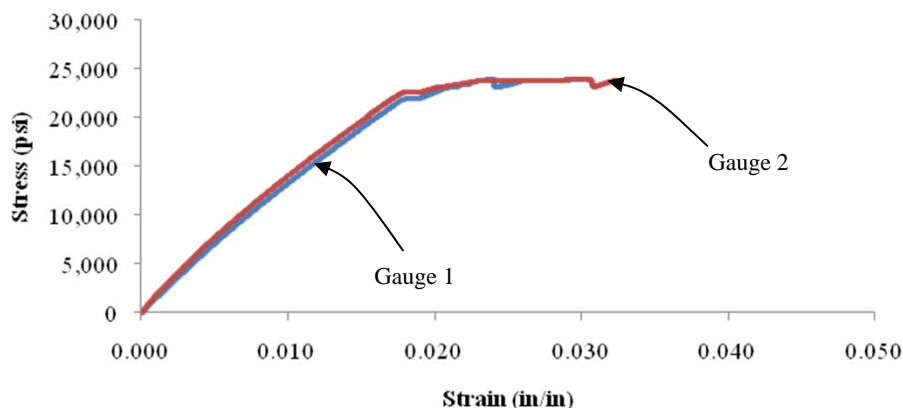
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00914 | 0.00339 | 1,278,559 |
| 2 | 0.00853 | 0.00300 | 1,332,050 |
| Average | | | 1,305,304 |

Stress-Strain Curve N40_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-N40-FY08
 Test Date: 8/2/11
 Specimen Received: 4/19/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 20,193 lbs
 Shear Strength, S_{xy} : 24,417 psi
 Shear Modulus, G_{xy} : 1,129,652 psi

Measured Specimen Dimensions:

Thickness, T: 1.43 in
 Notch Length, N: 0.58 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,039 lbs
 50% Max Load: 10,096 lbs

PICTURE OF SPECIMEN PRE-TEST



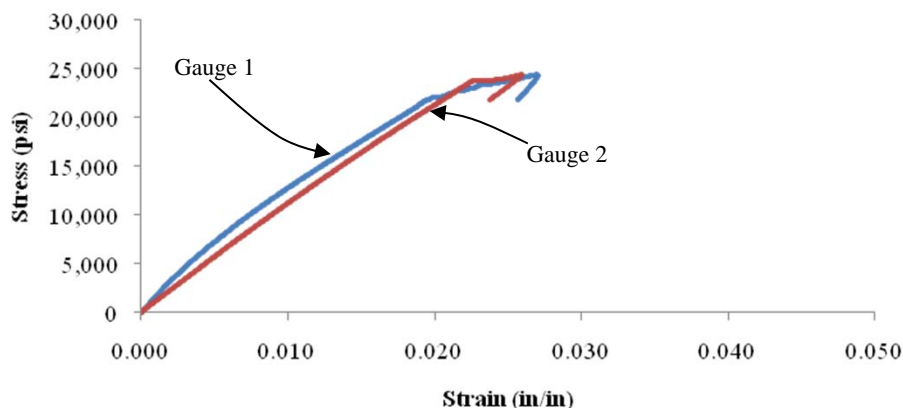
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00941 | 0.00312 | 1,164,974 |
| 2 | 0.01089 | 0.00420 | 1,094,330 |
| Average | | | 1,129,652 |

Stress-Strain Curve N40_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-N40-FY08
 Test Date: 8/2/11
 Specimen Received: 4/19/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 16,235 lbs
 Shear Strength, S_{xy} : 19,631 psi
 Shear Modulus, G_{xy} : 1,235,106 psi

Measured Specimen Dimensions:

Thickness, T: 1.43 in
 Notch Length, N: 0.58 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,247 lbs
 50% Max Load: 8,117 lbs

PICTURE OF SPECIMEN PRE-TEST



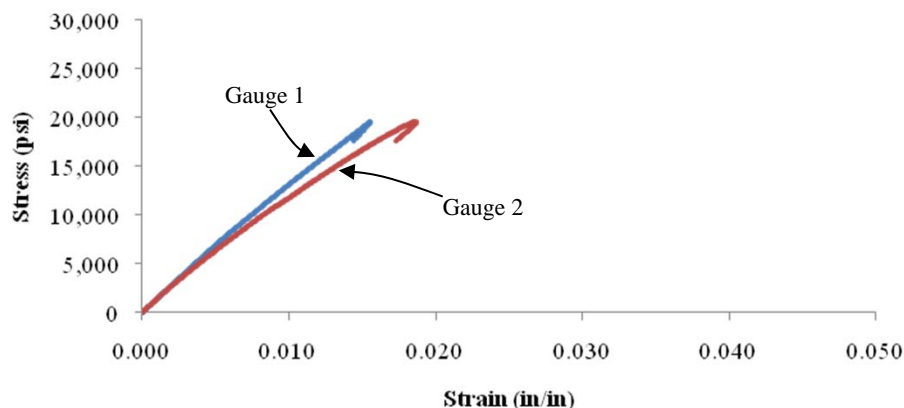
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00727 | 0.00279 | 1,314,602 |
| 2 | 0.00803 | 0.00294 | 1,155,609 |
| Average | | | 1,235,106 |

Stress-Strain Curve N40_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

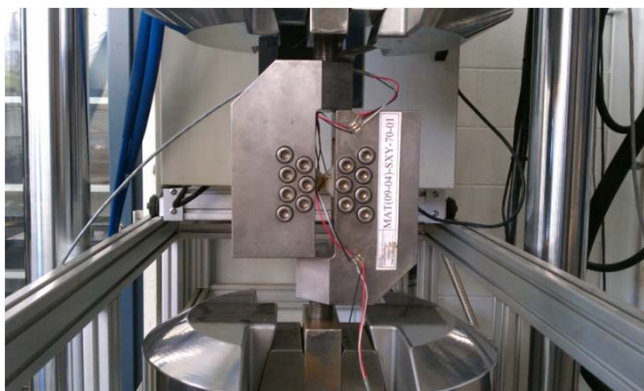
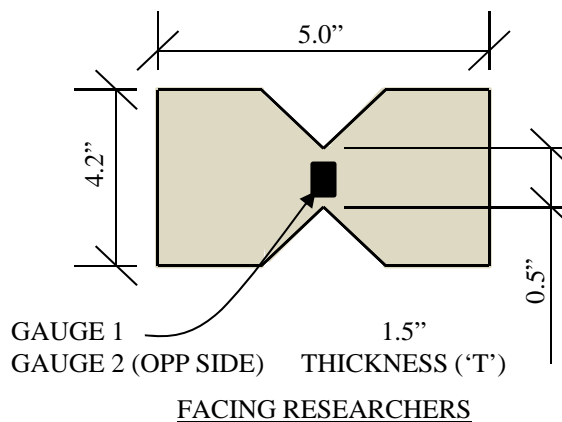
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXY-70-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **18,016** **lbs**
 Shear Strength, S_{xy} : **21,685** **psi**
 Shear Modulus, G_{xy} : **1,280,563** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT2-SXY-01-70-FY08 | 18,424 | 21,778 | 1,220,524 | Shear |
| 2 | MAT2-SXY-02-70-FY08 | 18,245 | 22,089 | 1,325,053 | Shear |
| 3 | MAT2-SXY-03-70-FY08 | 17,888 | 21,761 | 1,286,100 | Shear |
| 4 | MAT2-SXY-04-70-FY08 | 18,146 | 21,654 | 1,349,835 | Shear |
| 5 | MAT2-SXY-05-70-FY08 | 17,379 | 21,142 | 1,221,304 | Shear |
| Average | | 18,016 | 21,685 | 1,280,563 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-44 to C-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-70-FY08
 Test Date: 5/23/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,424 lbs
 Shear Stress, S_{xy} : 21,778 psi
 Shear Modulus, G_{xy} : 1,220,524 psi

Measured Specimen Dimensions:

Thickness, T: 1.42 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,685 lbs
 50% Max Load: 9,212 lbs

PICTURE OF SPECIMEN PRE-TEST



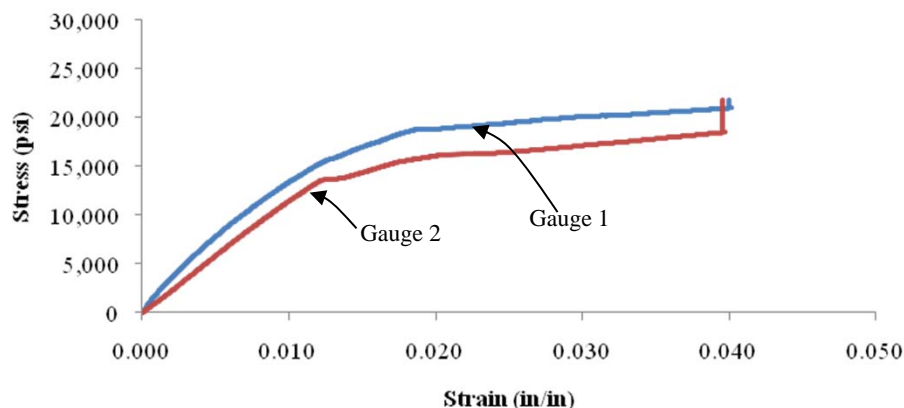
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0076 | 0.0025 | 1,292,471 |
| 2 | 0.0095 | 0.0038 | 1,148,578 |
| Average | | | 1,220,524 |

Stress-Strain Curve 70F_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-70-FY08
 Test Date: 5/23/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,245 lbs
 Shear Stress, S_{xy} : 22,089 psi
 Shear Modulus, G_{xy} : 1,325,053 psi

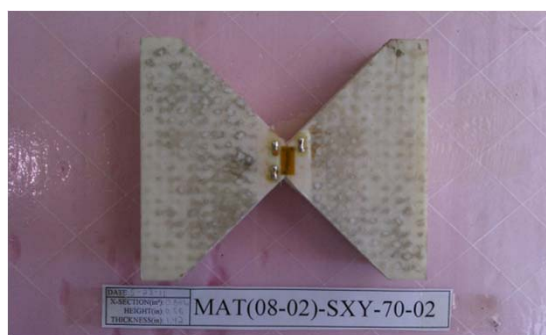
Measured Specimen Dimensions:

Thickness, T: 1.42 in
 Notch Length, N: 0.58 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,649 lbs
 50% Max Load: 9,123 lbs

PICTURE OF SPECIMEN PRE-TEST



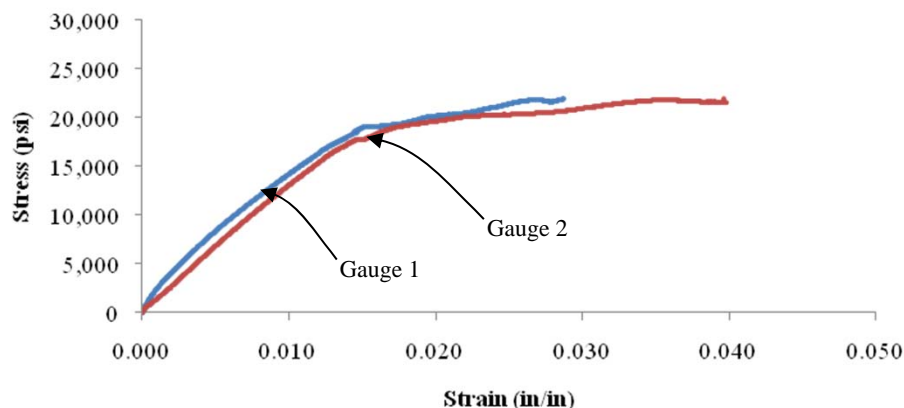
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0071 | 0.0022 | 1,336,255 |
| 2 | 0.0083 | 0.0032 | 1,313,851 |
| Average | | | 1,325,053 |

Stress-Strain Curve 70F_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-70-FY08
 Test Date: 5/23/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

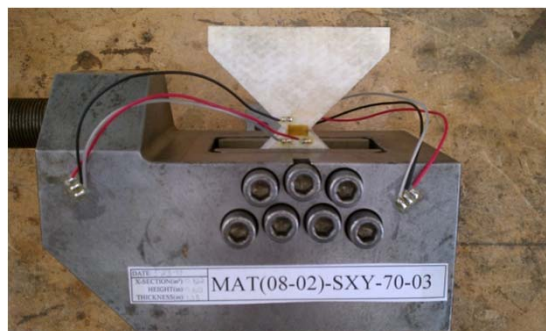
Average Material Properties:

Ultimate Load, P_{max} : 17,888 lbs
 Shear Stress, S_{xy} : 21,761 psi
 Shear Modulus, G_{xy} : 1,286,100 psi

Measured Specimen Dimensions:

Thickness, T: 1.98 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,578 lbs
 50% Max Load: 8,944 lbs

PICTURE OF SPECIMEN PRE-TEST



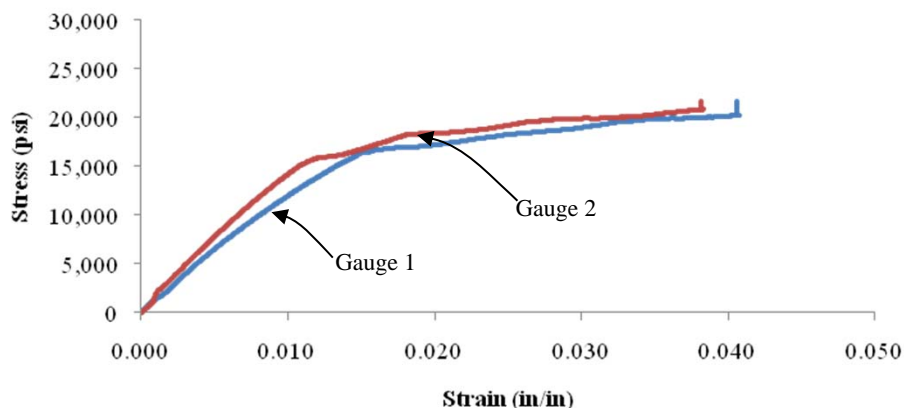
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0089 | 0.0033 | 1,159,966 |
| 2 | 0.0073 | 0.0026 | 1,412,235 |
| Average | | | 1,286,100 |

Stress-Strain Curve 70F_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-70-FY08
 Test Date: 5/23/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,146 lbs
 Shear Stress, S_{xy} : 21,654 psi
 Shear Modulus, G_{xy} : 1,349,835 psi

Measured Specimen Dimensions:

Thickness, T: 1.42 in
 Notch Length, N: 0.59 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,629 lbs
 50% Max Load: 9,073 lbs

PICTURE OF SPECIMEN PRE-TEST



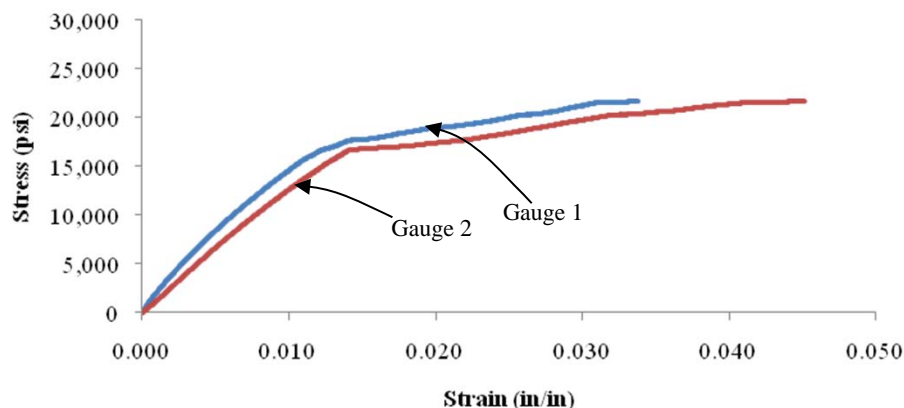
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0068 | 0.0023 | 1,439,824 |
| 2 | 0.0084 | 0.0032 | 1,259,846 |
| Average | | | 1,349,835 |

Stress-Strain Curve 70F_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-70-FY08
 Test Date: 5/23/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

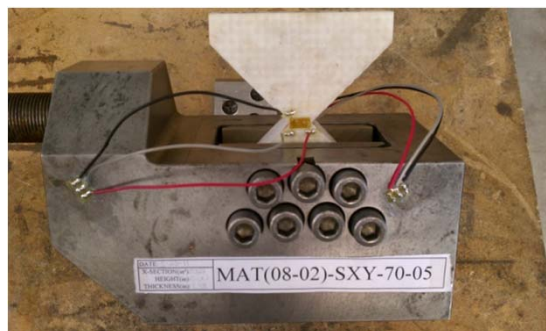
Average Material Properties:

Ultimate Load, P_{max} : 17,379 lbs
 Shear Stress, S_{xy} : 21,142 psi
 Shear Modulus, G_{xy} : 1,221,304 psi

Measured Specimen Dimensions:

Thickness, T: 1.38 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,476 lbs
 50% Max Load: 8,689 lbs

PICTURE OF SPECIMEN PRE-TEST



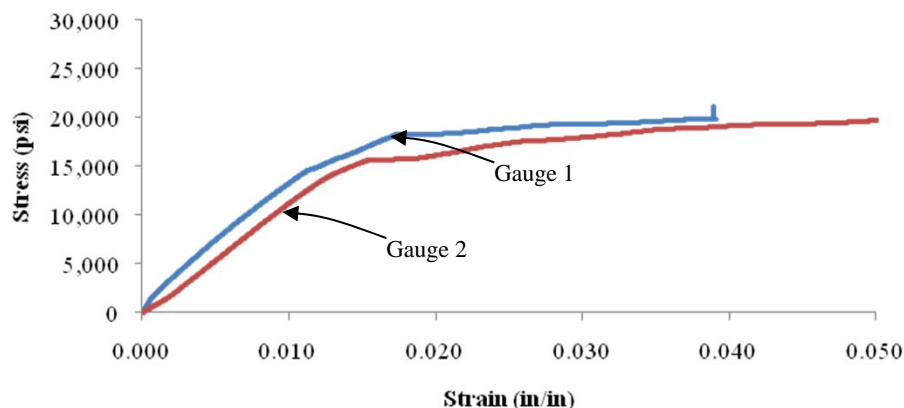
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0076 | 0.0025 | 1,260,374 |
| 2 | 0.0094 | 0.0041 | 1,182,235 |
| Average | | | 1,221,304 |

Stress-Strain Curve 70F_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

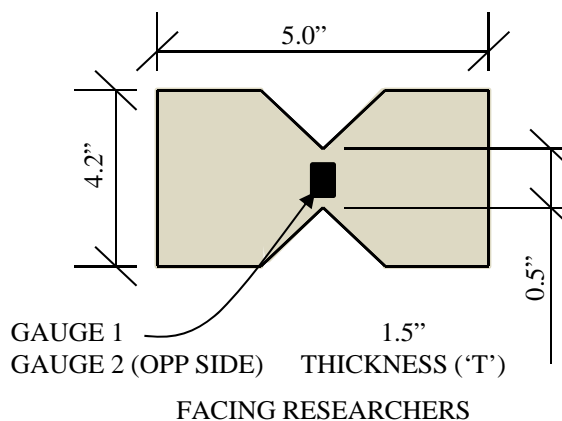
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXY-140-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **14,832** **lbs**
 Shear Strength, S_{xy} : **17,690** **psi**
 Shear Modulus, G_{xy} : **846,113** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT2-SXY-01-140-FY08 | 14,326 | 16,974 | 868,165 | Shear |
| 2 | MAT2-SXY-02-140-FY08 | 15,014 | 17,622 | 765,581 | Shear |
| 3 | MAT2-SXY-03-140-FY08 | 15,594 | 18,303 | 811,379 | Shear |
| 4 | MAT2-SXY-04-140-FY08 | 14,318 | 17,611 | 806,843 | Shear |
| 5 | MAT2-SXY-05-140-FY08 | 14,909 | 17,941 | 978,599 | Shear |
| Average | | 14,832 | 17,690 | 846,113 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-50 to C-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-140-FY08
 Test Date: 5/13/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 14,326 lbs
 Shear Stress, S_{xy} : 16,974 psi
 Shear Modulus, G_{xy} : 868,165 psi

Measured Specimen Dimensions:

Thickness, T: 1.43 in
 Notch Length, N: 0.59 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,865 lbs
 50% Max Load: 7,163 lbs

PICTURE OF SPECIMEN PRE-TEST



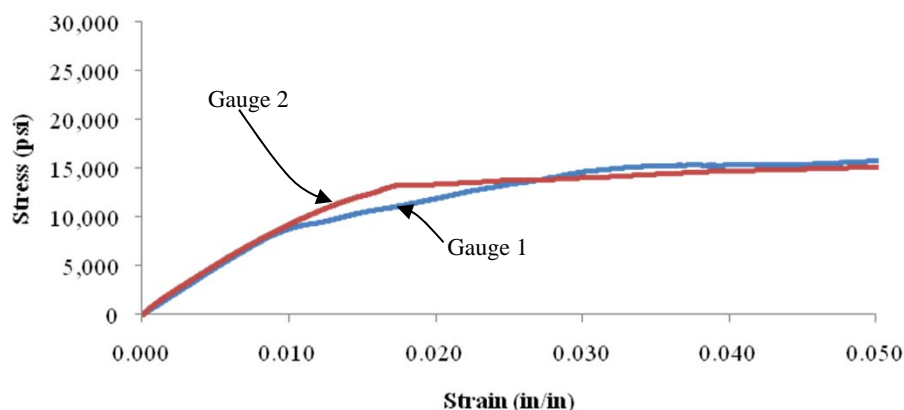
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0094 | 0.0035 | 862,186 |
| 2 | 0.0090 | 0.0032 | 874,145 |
| Average | | | 868,165 |

Stress-Strain Curve 140F_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-140-FY08
 Test Date: 5/13/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 15,014 lbs
 Shear Stress, S_{xy} : 17,622 psi
 Shear Modulus, G_{xy} : 765,581 psi

Measured Specimen Dimensions:

Thickness, T: 1.41 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,003 lbs
 50% Max Load: 7,507 lbs

PICTURE OF SPECIMEN PRE-TEST



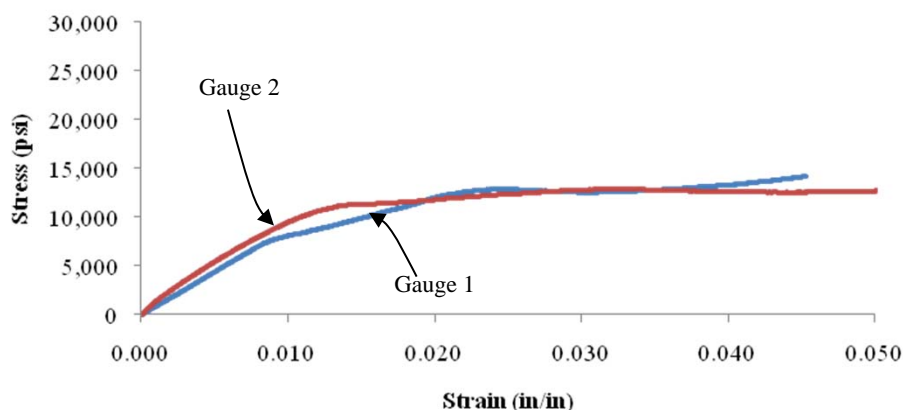
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0121 | 0.0040 | 652,573 |
| 2 | 0.0090 | 0.0030 | 878,588 |
| Average | | | 765,581 |

Stress-Strain Curve 140F_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-140-FY08
 Test Date: 5/16/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 15,594 lbs
 Shear Stress, S_{xy} : 18,303 psi
 Shear Modulus, G_{xy} : 811,379 psi

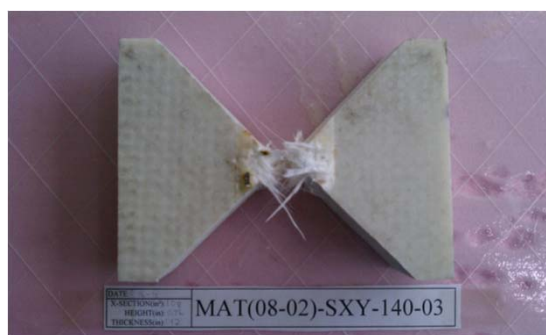
Measured Specimen Dimensions:

Thickness, T: 1.42 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,119 lbs
 50% Max Load: 7,797 lbs

PICTURE OF SPECIMEN PRE-TEST



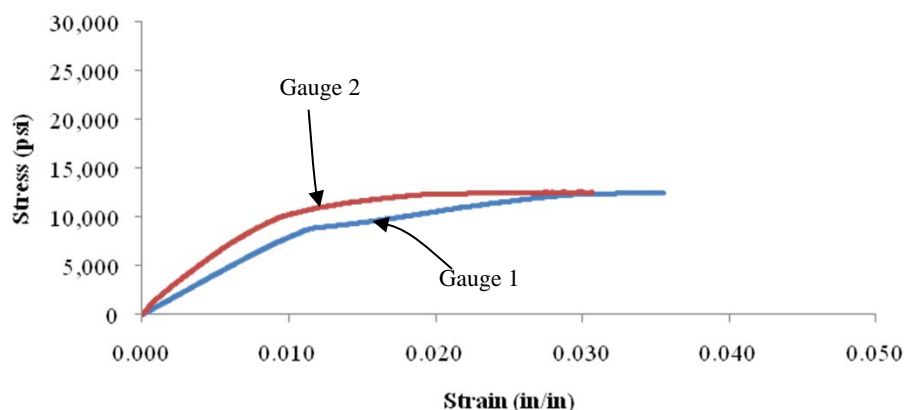
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0132 | 0.0044 | 625,156 |
| 2 | 0.0082 | 0.0027 | 997,602 |
| Average | | | 811,379 |

Stress-Strain Curve 140F_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-140-FY08
 Test Date: 5/16/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 14,318 lbs
 Shear Stress, S_{xy} : 17,611 psi
 Shear Modulus, G_{xy} : 806,843 psi

Measured Specimen Dimensions:

Thickness, T: 1.40 in
 Notch Length, N: 0.58 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,864 lbs
 50% Max Load: 7,159 lbs

PICTURE OF SPECIMEN PRE-TEST



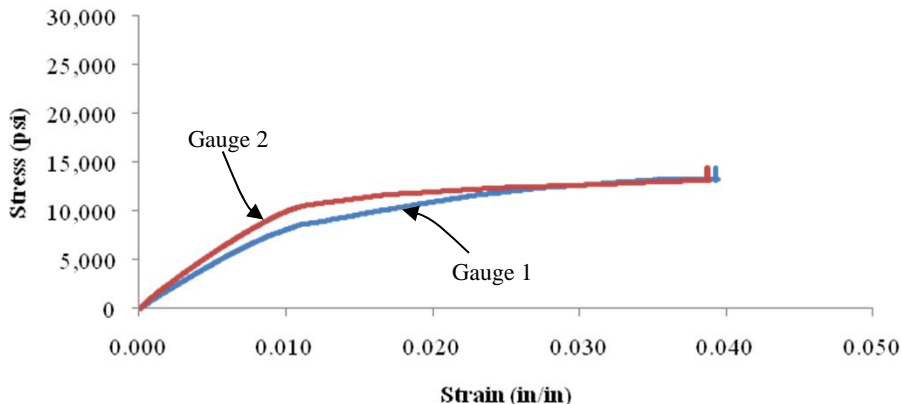
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0119 | 0.0038 | 650,823 |
| 2 | 0.0084 | 0.0029 | 962,862 |
| Average | | | 806,843 |

Stress-Strain Curve 140F_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-140-FY08
 Test Date: 5/16/2011
 Specimen Received: 4/19/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 14,909 lbs
 Shear Stress, S_{xy} : 17,941 psi
 Shear Modulus, G_{xy} : 978,599 psi

Measured Specimen Dimensions:

Thickness, T: 1.41 in
 Notch Length, N: 0.59 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,982 lbs
 50% Max Load: 7,455 lbs

PICTURE OF SPECIMEN PRE-TEST



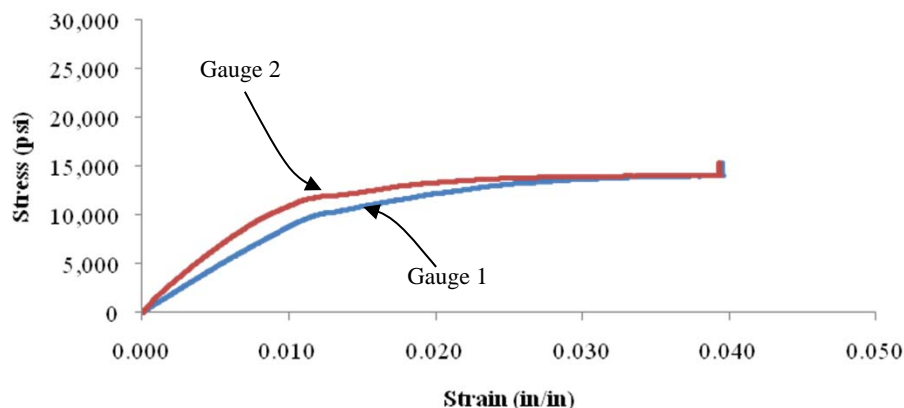
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0102 | 0.0038 | 846,461 |
| 2 | 0.0073 | 0.0025 | 1,111,038 |
| Average | | | 978,599 |

Stress-Strain Curve 140F_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TZ-N40-FY08

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 1,917 lbs

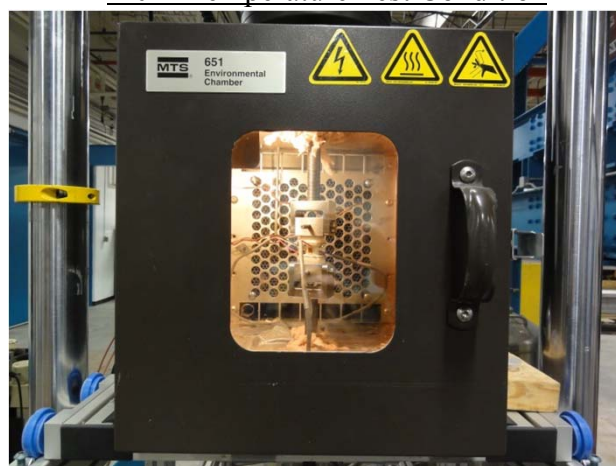
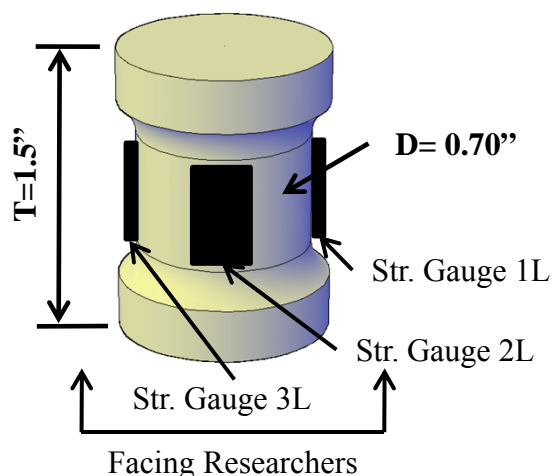
Tensile Strength, ST_z : 4,970 psi

Tensile Modulus, E_z : 1,303,324 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT2-TZ-1-N40-FY08 | 2,073 | 5,371 | 1,283,852 | Rupture |
| MAT2-TZ-2-N40-FY08 | 1,812 | 4,668 | 1,242,402 | Rupture |
| MAT2-TZ-3-N40-FY08 | 1,964 | 5,089 | 1,404,829 | Rupture |
| MAT2-TZ-4-N40-FY08 | 1,861 | 4,849 | 1,312,936 | Rupture |
| MAT2-TZ-5-N40-FY08 | 1,876 | 4,875 | 1,272,602 | Rupture |
| Average | 1,917 | 4,970 | 1,303,324 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference C-56 to C-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-1-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

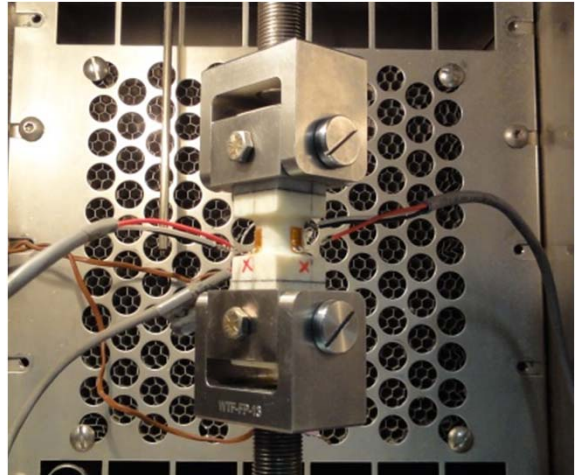
Average Material Properties:

Tensile Strength, ST_z : 5,371 psi
 Tensile Modulus, E_z : 1,283,852 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,685 psi
 20% Max Stress: 1,074 psi

PICTURE OF SPECIMEN PRE-TEST

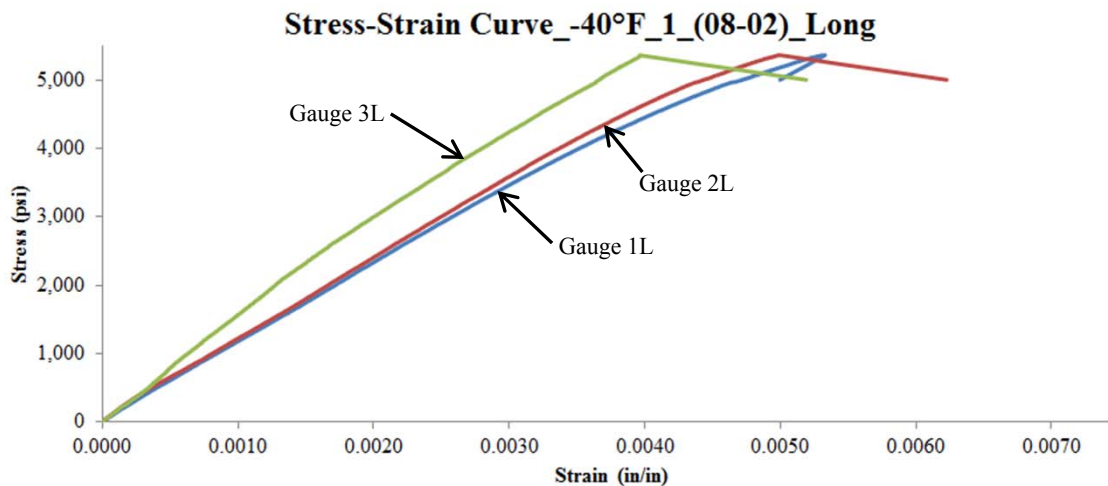


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002297 | 0.000909 | 1,160,601 |
| 2L | 0.002228 | 0.000875 | 1,190,478 |
| 3L | 0.001755 | 0.000681 | 1,500,478 |
| Average | | | 1,283,852 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

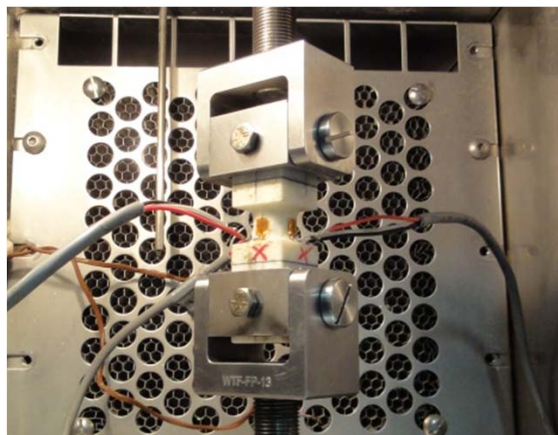
Average Material Properties:

Tensile Strength, ST_z : 4,668 psi
 Tensile Modulus, E_z : 1,242,402 psi

Measured Specimen Dimensions:

Diameter, D: 0.703 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,334 psi
 20% Max Stress: 934 psi

PICTURE OF SPECIMEN PRE-TEST

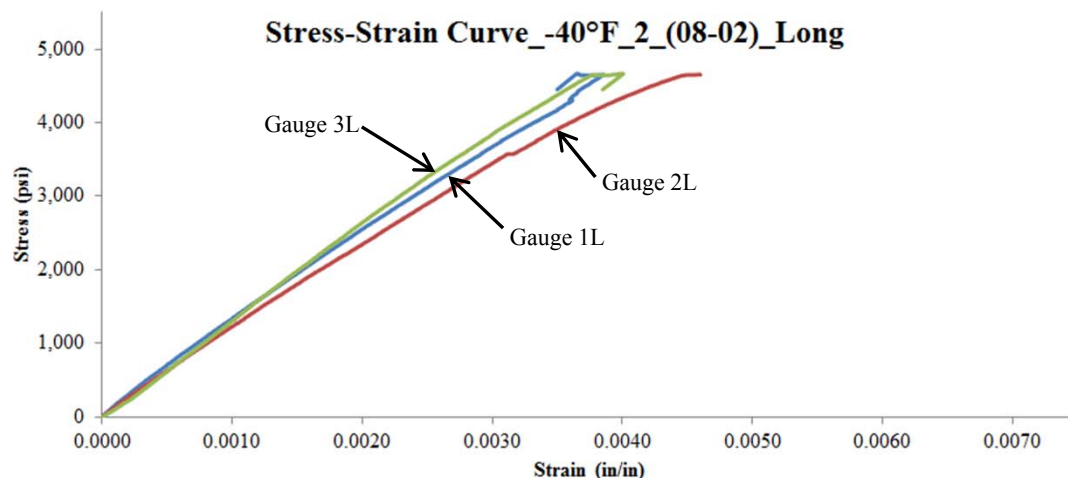


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001811 | 0.000676 | 1,234,009 |
| 2L | 0.001985 | 0.000749 | 1,133,406 |
| 3L | 0.001760 | 0.000730 | 1,359,792 |
| Average | | | 1,242,402 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

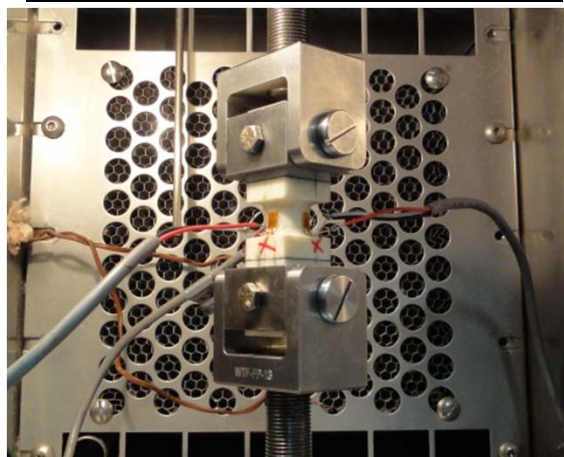
Average Material Properties:

Tensile Strength, ST_z : 5,089 psi
 Tensile Modulus, E_z : 1,404,829 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,544 psi
 20% Max Stress: 1,018 psi

PICTURE OF SPECIMEN PRE-TEST

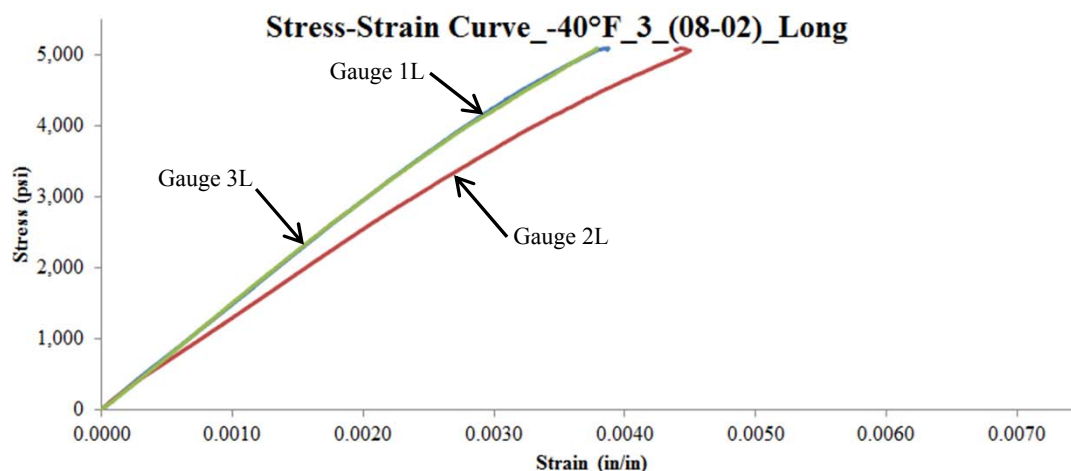


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001713 | 0.000681 | 1,478,556 |
| 2L | 0.002002 | 0.000777 | 1,246,419 |
| 3L | 0.001705 | 0.000681 | 1,489,511 |
| Average | | | 1,404,829 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

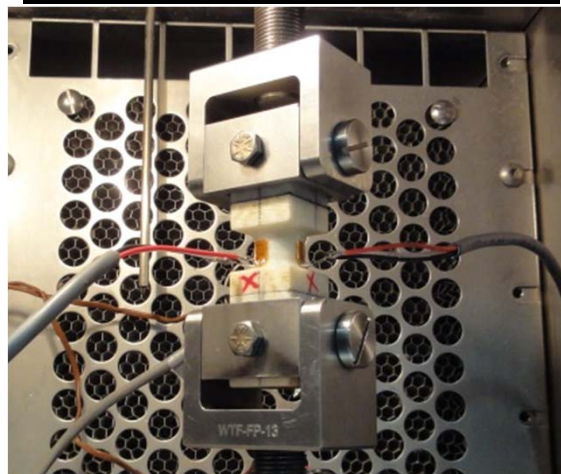
Average Material Properties:

Tensile Strength, ST_z : 4,849 psi
 Tensile Modulus, E_z : 1,312,936 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,424 psi
 20% Max Stress: 970 psi

PICTURE OF SPECIMEN PRE-TEST

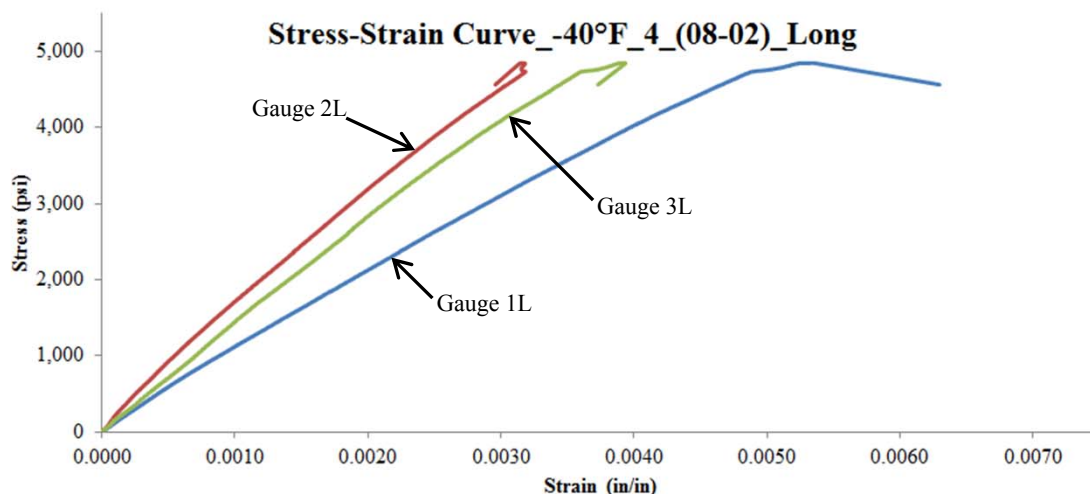


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002294 | 0.000851 | 1,008,669 |
| 2L | 0.001481 | 0.000526 | 1,523,147 |
| 3L | 0.001719 | 0.000685 | 1,406,994 |
| Average | | | 1,312,936 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

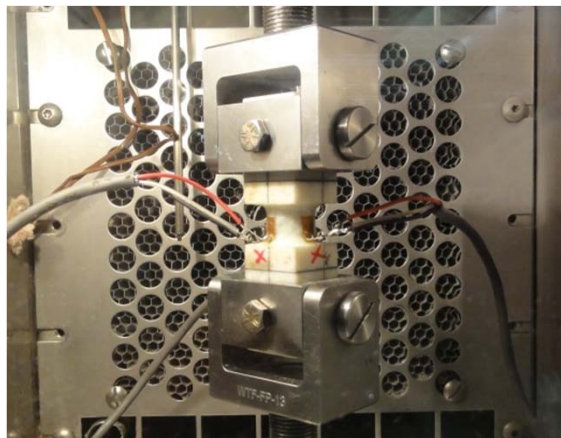
Average Material Properties:

Tensile Strength, ST_z : 4,875 psi
 Tensile Modulus, E_z : 1,272,602 psi

Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,437 psi
 20% Max Stress: 975 psi

PICTURE OF SPECIMEN PRE-TEST

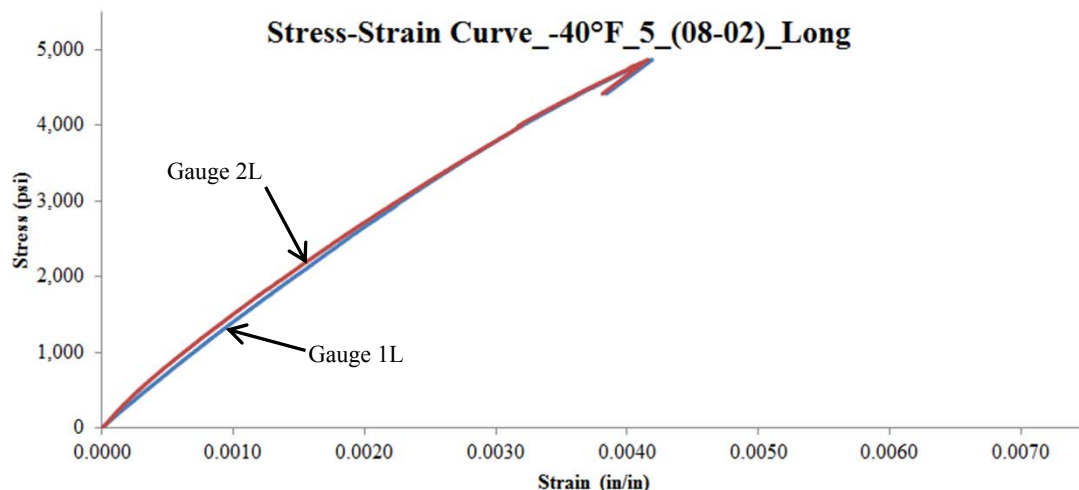


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001820 | 0.000677 | 1,279,650 |
| 2L | 0.001758 | 0.000603 | 1,265,553 |
| 3L | Lost Gauge | | |
| Average | | | 1,272,602 |



Engineering Test notes:

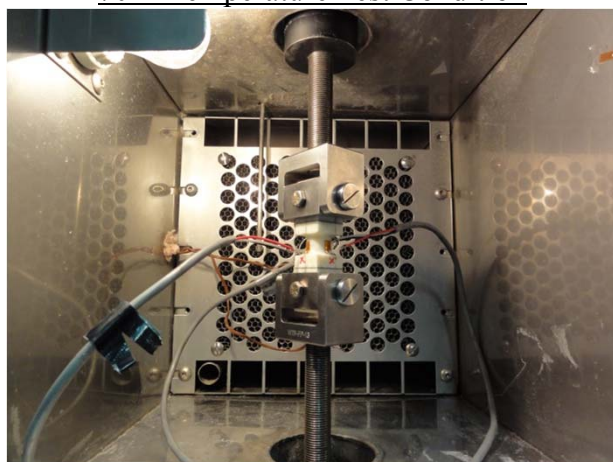
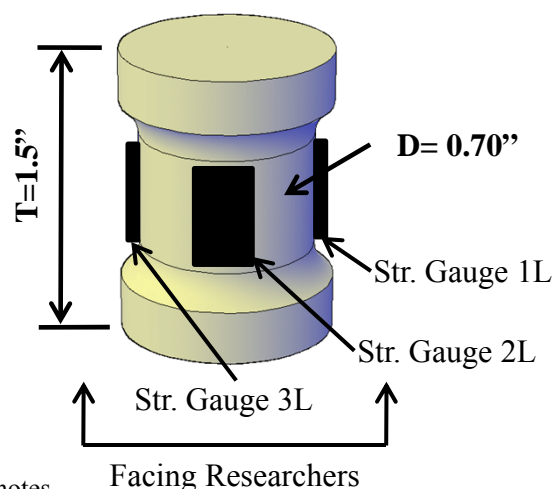
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT2-TZ-70-FY08**Material:** Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**Nominal Temperature:** 70°F**Properties Measured:** ST_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 1,394 lbs**Tensile Strength, ST_z :** 3,623 psi**Tensile Modulus, E_z :** 1,077,525 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT2-TZ-1-70-FY08 | 1,481 | 3,837 | 1,153,278 | Rupture |
| MAT2-TZ-2-70-FY08 | 1,273 | 3,308 | 1,056,580 | Rupture |
| MAT2-TZ-3-70-FY08 | 1,428 | 3,721 | 1,051,626 | Rupture |
| MAT2-TZ-4-70-FY08 | 1,329 | 3,463 | 1,092,147 | Rupture |
| MAT2-TZ-5-70-FY08 | 1,461 | 3,787 | 1,033,997 | Rupture |
| Average | 1,394 | 3,623 | 1,077,525 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference C-62 to C-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-1-70-FY08**
 Test Date: 7/19/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

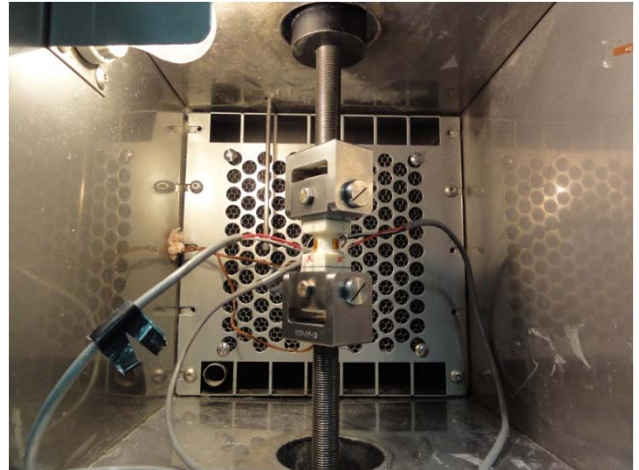
Average Material Properties:

Tensile Strength, ST_z : 3,837 psi
 Tensile Modulus, E_z : 1,153,278 psi

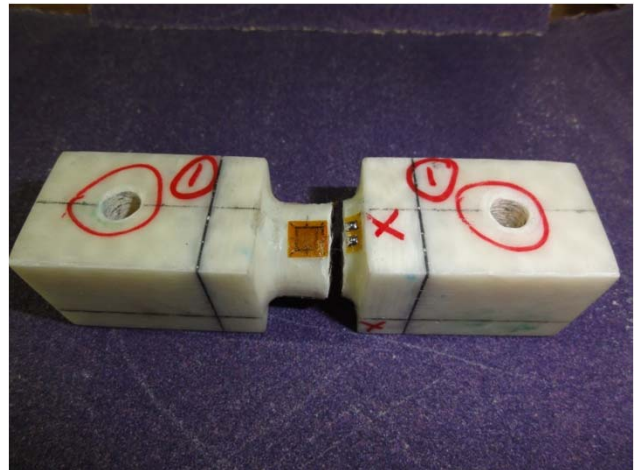
Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,919 psi
 20% Max Stress: 767 psi

PICTURE OF SPECIMEN PRE-TEST



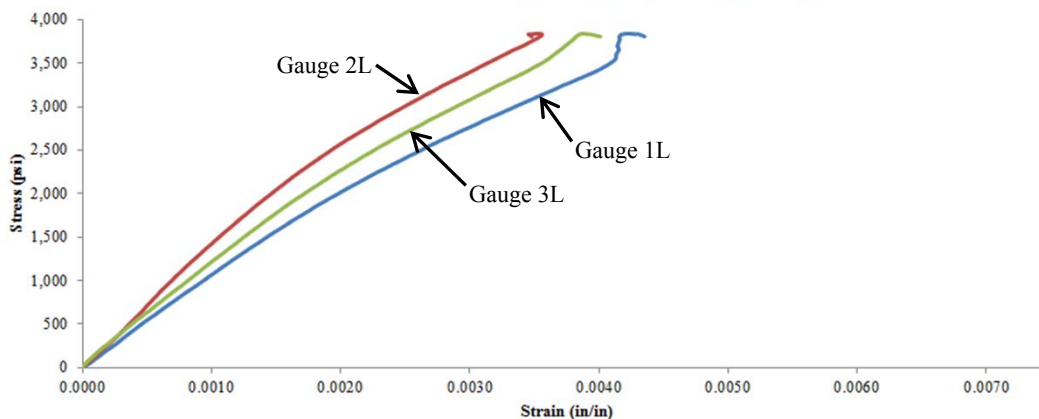
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001880 | 0.000710 | 984,051 |
| 2L | 0.001389 | 0.000534 | 1,346,163 |
| 3L | 0.001633 | 0.000614 | 1,129,620 |
| Average | | | 1,153,278 |

Stress-Strain Curve_70°F_1_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-70-FY08**
 Test Date: 7/19/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

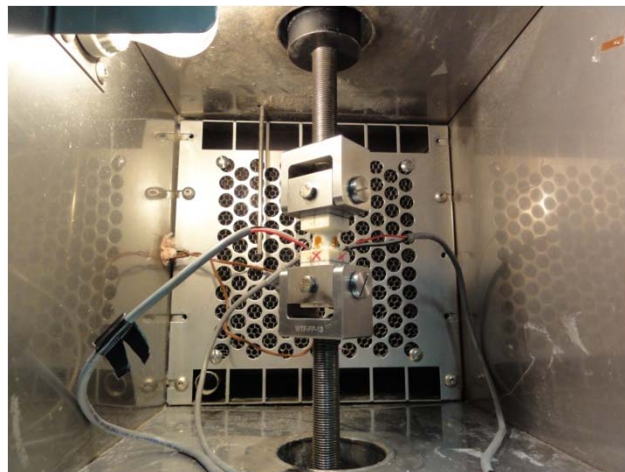
Average Material Properties:

Tensile Strength, ST_z : 3,308 psi
 Tensile Modulus, E_z : 1,056,580 psi

Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,654 psi
 20% Max Stress: 662 psi

PICTURE OF SPECIMEN PRE-TEST



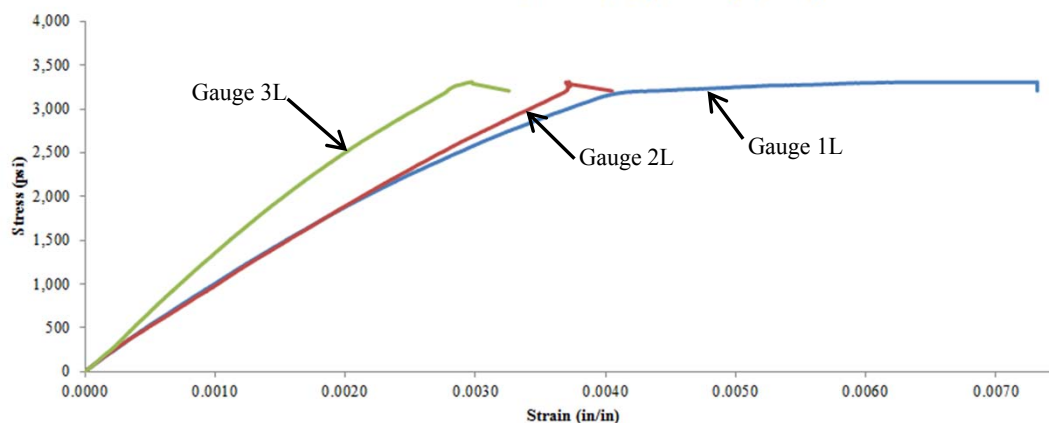
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001719 | 0.000636 | 915,760 |
| 2L | 0.001727 | 0.000656 | 926,839 |
| 3L | 0.001232 | 0.000485 | 1,327,140 |
| Average | | | 1,056,580 |

Stress-Strain Curve_70°F_2_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-70-FY08**
 Test Date: 7/19/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

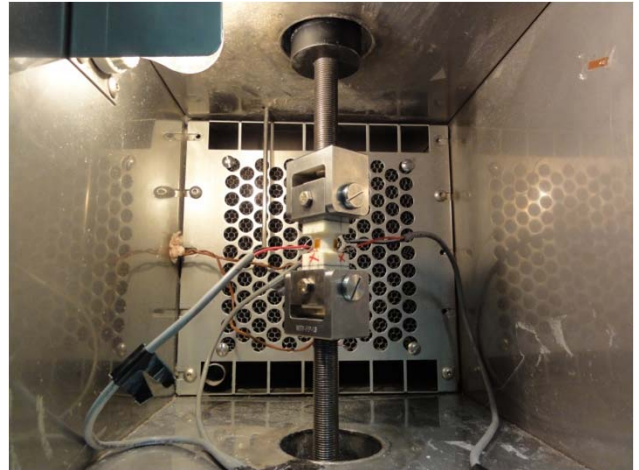
Average Material Properties:

Tensile Strength, ST_z : 3,721 psi
 Tensile Modulus, E_z : 1,051,626 psi

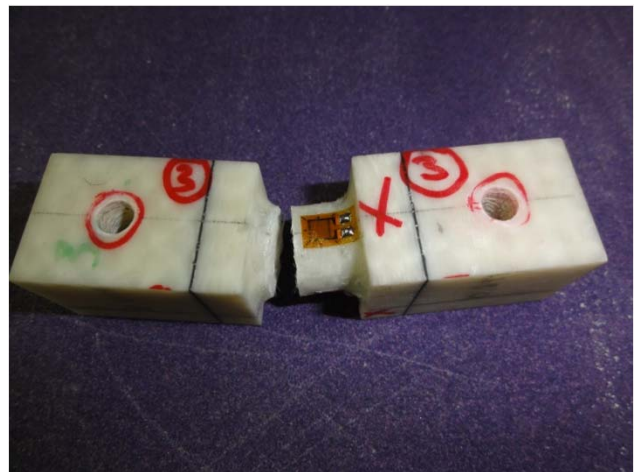
Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,861 psi
 20% Max Stress: 744 psi

PICTURE OF SPECIMEN PRE-TEST



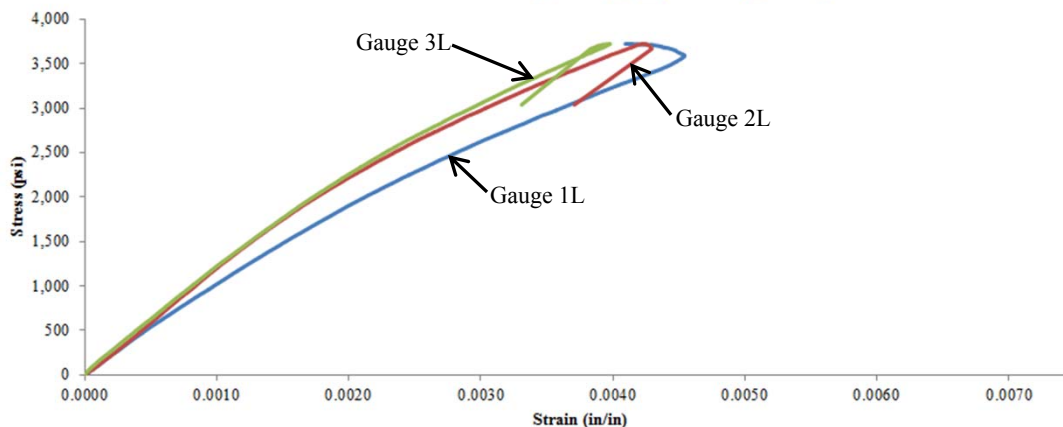
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001946 | 0.000706 | 900,275 |
| 2L | 0.001610 | 0.000624 | 1,132,894 |
| 3L | 0.001590 | 0.000595 | 1,121,708 |
| Average | | | 1,051,626 |

Stress-Strain Curve_70°F_3_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-70-FY08**
 Test Date: 7/19/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

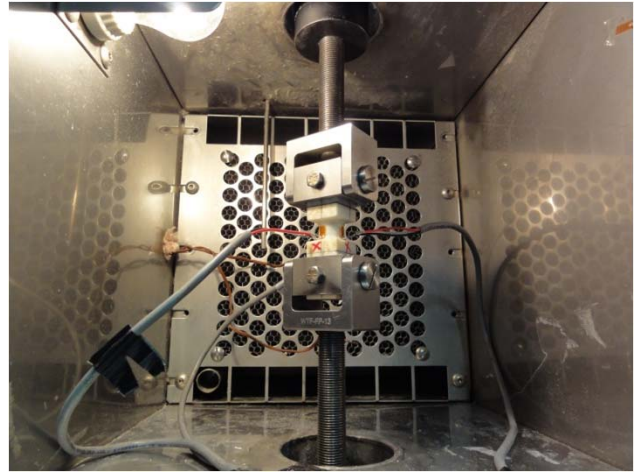
Average Material Properties:

Tensile Strength, ST_z : 3,463 psi
 Tensile Modulus, E_z : 1,092,147 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,731 psi
 20% Max Stress: 693 psi

PICTURE OF SPECIMEN PRE-TEST



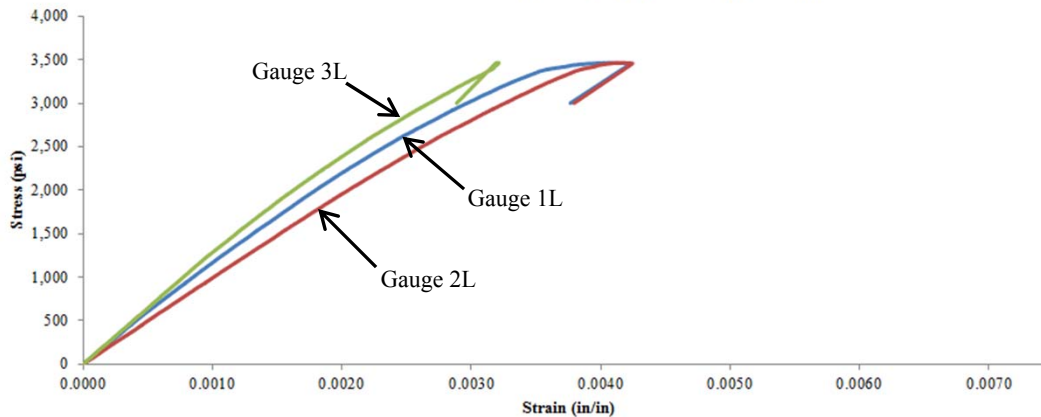
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001534 | 0.000572 | 1,079,718 |
| 2L | 0.001760 | 0.000693 | 973,305 |
| 3L | 0.001381 | 0.000532 | 1,223,416 |
| Average | | | 1,092,147 |

Stress-Strain Curve_70°F_4_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-70-FY08**
 Test Date: 7/19/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

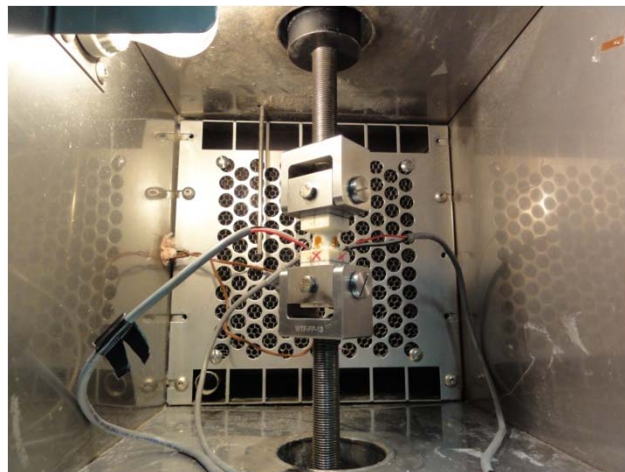
Average Material Properties:

Tensile Strength, ST_z : 3,787 psi
 Tensile Modulus, E_z : 1,033,997 psi

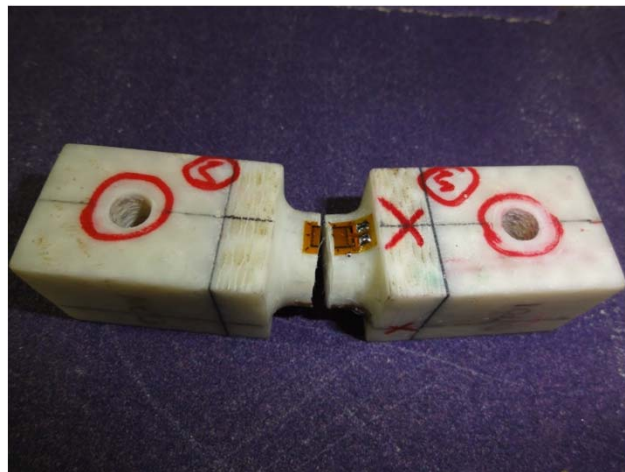
Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,893 psi
 20% Max Stress: 757 psi

PICTURE OF SPECIMEN PRE-TEST



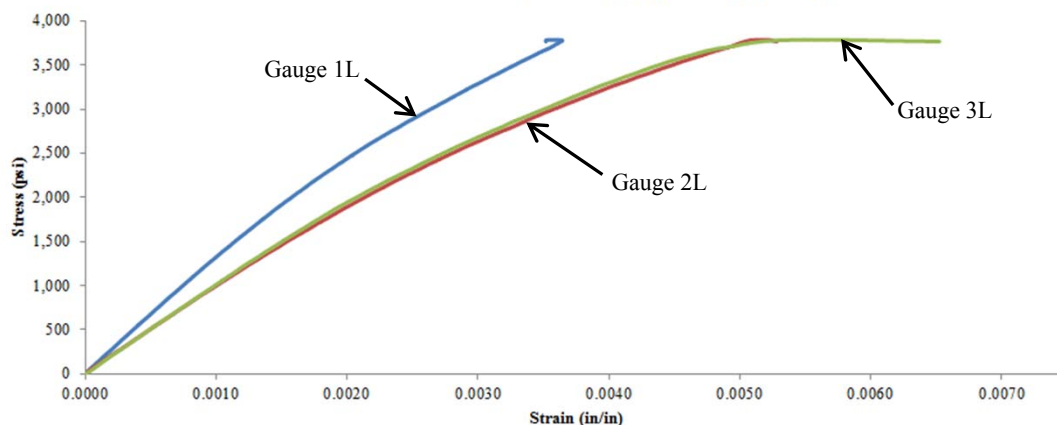
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001477 | 0.000560 | 1,239,085 |
| 2L | 0.002001 | 0.000751 | 908,780 |
| 3L | 0.001939 | 0.000748 | 954,126 |
| Average | | | 1,033,997 |

Stress-Strain Curve_70°F_5_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TZ-140-FY08

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 140°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 729 lbs

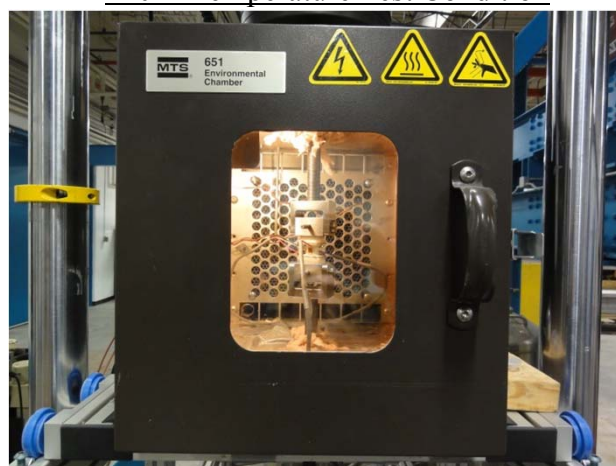
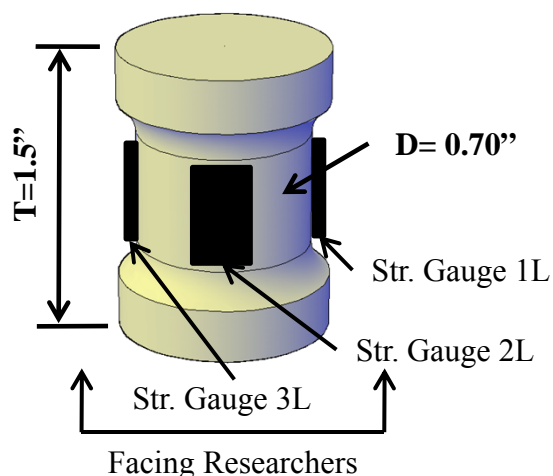
Tensile Strength, ST_z : 1,905 psi

Tensile Modulus, E_z : 230,915 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT2-TZ-1-140-FY08 | 677 | 1,774 | 215,583 | Rupture |
| MAT2-TZ-2-140-FY08 | 790 | 2,065 | 259,191 | Rupture |
| MAT2-TZ-3-140-FY08 | 717 | 1,870 | 202,742 | Rupture |
| MAT2-TZ-4-140-FY08 | 738 | 1,930 | 234,039 | Rupture |
| MAT2-TZ-5-140-FY08 | 724 | 1,888 | 243,019 | Rupture |
| Average | 729 | 1,905 | 230,915 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference C-68 to C-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-1-140-FY08**
 Test Date: 7/17/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

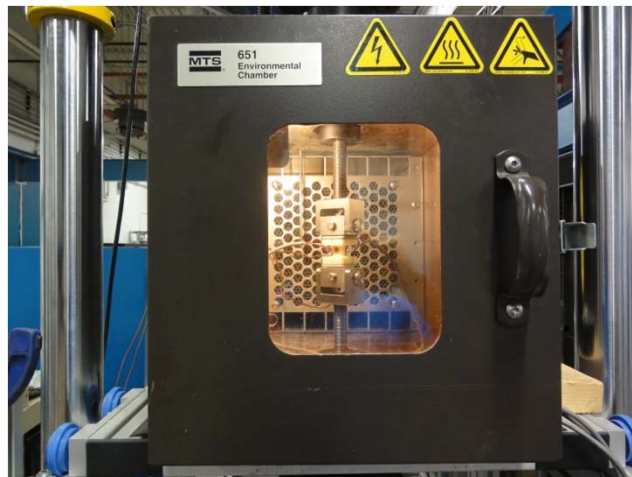
Average Material Properties:

Tensile Strength, ST_z : 1,774 psi
 Tensile Modulus, E_z : 215,583 psi

Measured Specimen Dimensions:

Diameter, D: 0.697 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 887 psi
 20% Max Stress: 355 psi

PICTURE OF SPECIMEN PRE-TEST



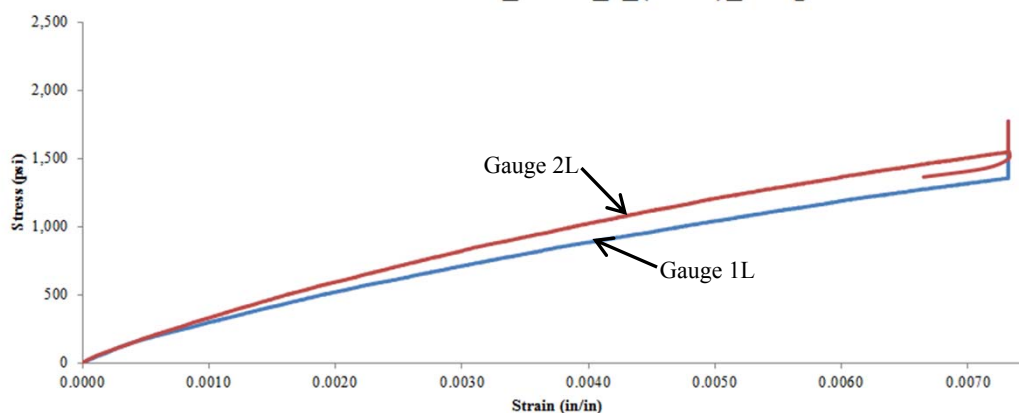
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.004016 | 0.001248 | 192,311 |
| 2L | 0.003310 | 0.001082 | 238,856 |
| 3L | Lost Gauge | | |
| Average | | | 215,583 |

Stress-Strain Curve_140°F_1_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-140-FY08**
 Test Date: 7/17/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,065 psi
 Tensile Modulus, E_z : 259,191 psi

Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,032 psi
 20% Max Stress: 413 psi

PICTURE OF SPECIMEN PRE-TEST



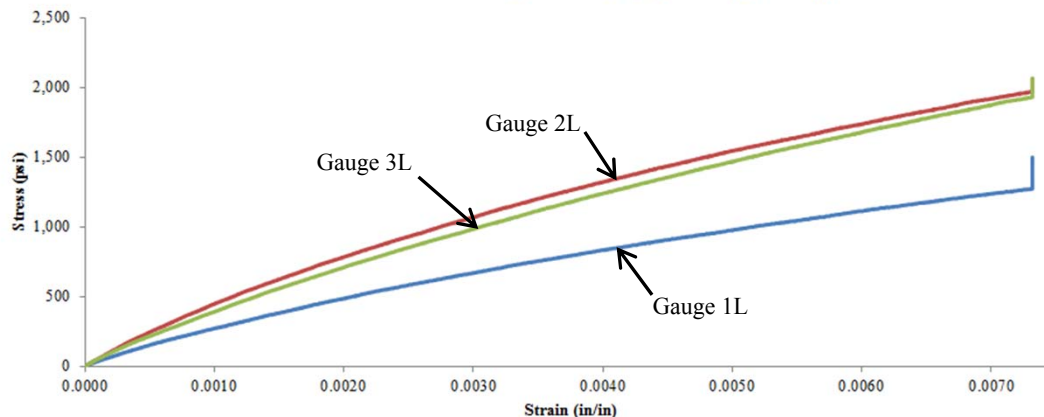
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.005385 | 0.001642 | 165,496 |
| 2L | 0.002855 | 0.000912 | 318,816 |
| 3L | 0.003173 | 0.001060 | 293,262 |
| Average | | | 259,191 |

Stress-Strain Curve_140°F_2_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-140-FY08**
 Test Date: 7/17/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,870 psi
 Tensile Modulus, E_z : 202,742 psi

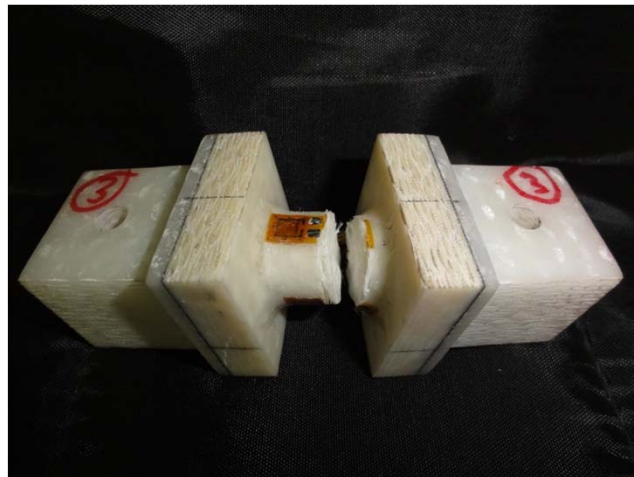
Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 935 psi
 20% Max Stress: 374 psi

PICTURE OF SPECIMEN PRE-TEST



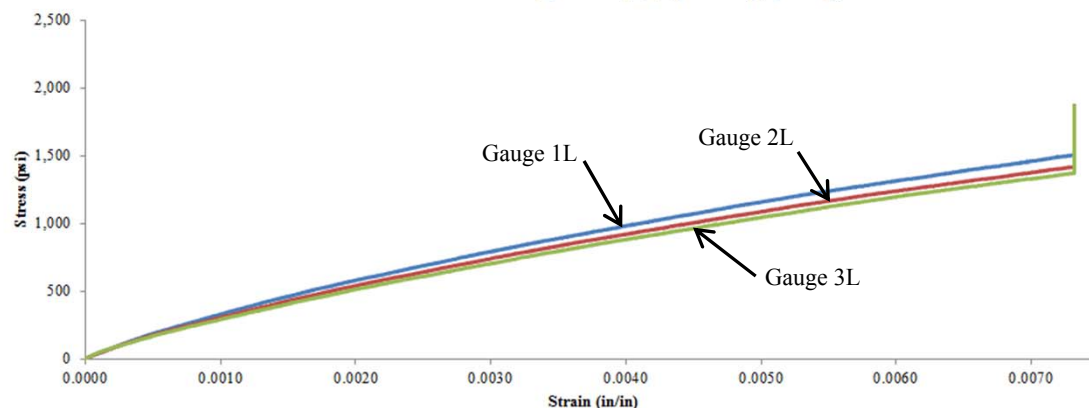
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.003730 | 0.001156 | 217,850 |
| 2L | 0.004066 | 0.001269 | 200,509 |
| 3L | 0.004306 | 0.001351 | 189,868 |
| Average | | | 202,742 |

Stress-Strain Curve_140°F_3_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-140-FY08**
 Test Date: 7/17/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,930 psi
 Tensile Modulus, E_z : 234,039 psi

Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 965 psi
 20% Max Stress: 386 psi

PICTURE OF SPECIMEN PRE-TEST



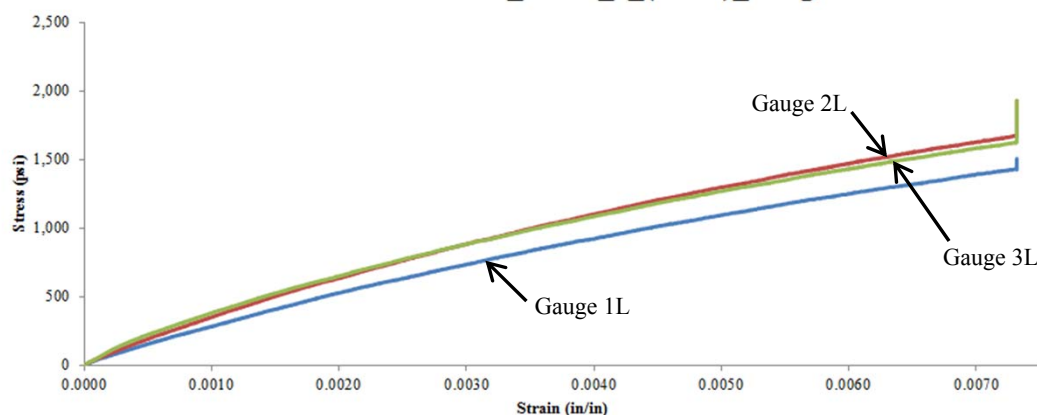
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.004233 | 0.001397 | 204,149 |
| 2L | 0.003367 | 0.001102 | 255,604 |
| 3L | 0.003396 | 0.001007 | 242,364 |
| Average | | | 234,039 |

Stress-Strain Curve_140°F_4_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-140-FY08**
 Test Date: 7/17/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_z , E_z

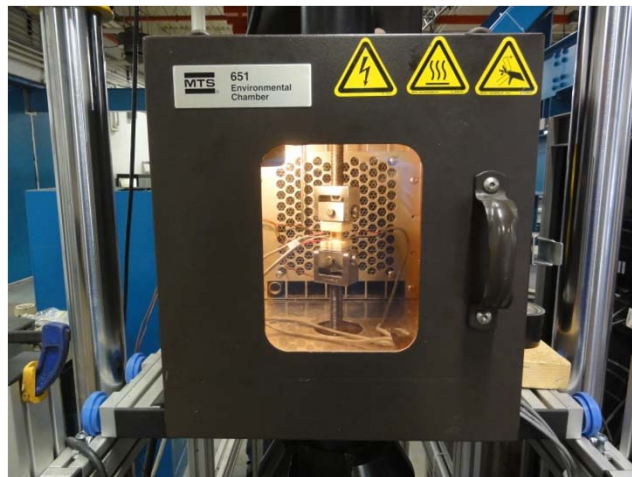
Average Material Properties:

Tensile Strength, ST_z : 1,888 psi
 Tensile Modulus, E_z : 243,019 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 944 psi
 20% Max Stress: 378 psi

PICTURE OF SPECIMEN PRE-TEST



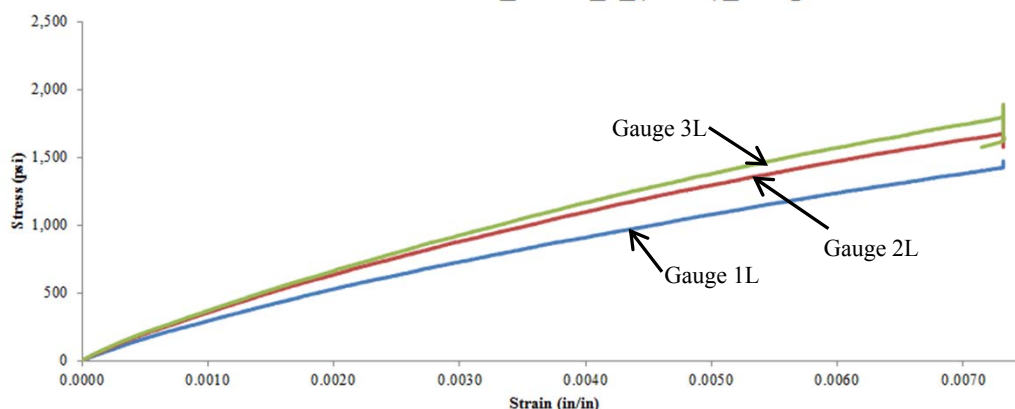
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.004191 | 0.001333 | 198,141 |
| 2L | 0.003287 | 0.001066 | 254,983 |
| 3L | 0.003070 | 0.001018 | 275,931 |
| Average | | | 243,019 |

Stress-Strain Curve_140°F_5_(08-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

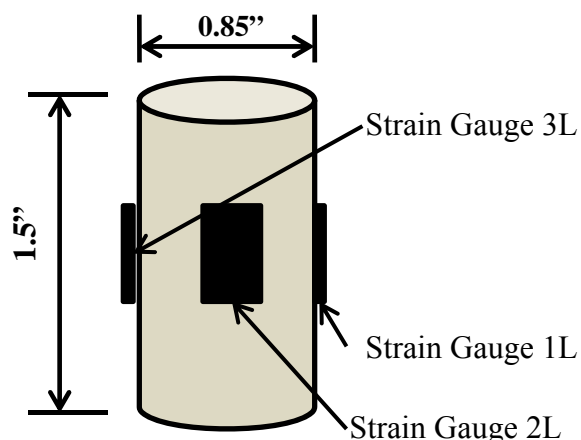
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CZ-N40-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 36,843 lbs
 Compressive Strength, SC_z : 65,513 psi
 Compressive Modulus, E_z : 1,165,695 psi
 Ultimate Strain, ϵ_z : 0.057 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT2-CZ-01-N40-FY08 | 43,058 | 76,616 | 1,101,384 | 0.070 | Rupture |
| MAT2-CZ-02-N40-FY08 | 42,789 | 76,137 | 1,072,651 | 0.071 | Rupture |
| MAT2-CZ-03-N40-FY08 | 30,913 | 55,006 | 1,125,664 | 0.049 | Rupture |
| MAT2-CZ-04-N40-FY08 | 34,257 | 60,633 | 1,360,133 | 0.045 | Rupture |
| MAT2-CZ-05-N40-FY08 | 33,196 | 59,173 | 1,168,644 | 0.051 | Rupture |
| Average | 36,843 | 65,513 | 1,165,695 | 0.057 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for the Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Facing Researchers****Notes:**

- 1) Reference C-74 to C-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-N40-FY08**
 Test Date: 11/30/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 43,058 lbs
 Maximum Stress, SC_z : 76,616 psi
 Compressive Modulus, E_z : 1,101,384 psi
 Ultimate Strain, ϵ_z : 0.070 in/in

Measured Specimen Dimensions:

Length, L: 1.373 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,612 psi
 50% Max Load: 21,529 psi

PICTURE OF SPECIMEN PRE-TEST



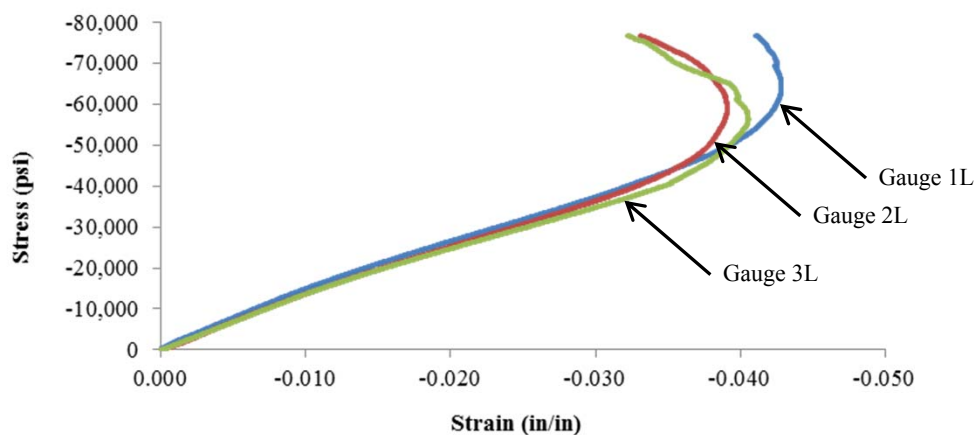
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.03083 | -0.01028 | 1,118,618 |
| 2L | -0.03158 | -0.01134 | 1,135,402 |
| 3L | -0.03326 | -0.01137 | 1,050,131 |
| Average | | | 1,101,384 |

Stress-Strain Curve N40_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-N40-FY-08**
 Test Date: 11/30/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 42,789 lbs
 Maximum Stress, SC_z : 76,137 psi
 Compressive Modulus, E_z : 1,072,651 psi
 Ultimate Strain, ϵ_z : 0.071 in/in

Measured Specimen Dimensions:

Length, L: 1.373 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,558 psi
 50% Max Load: 21,394 psi

PICTURE OF SPECIMEN PRE-TEST



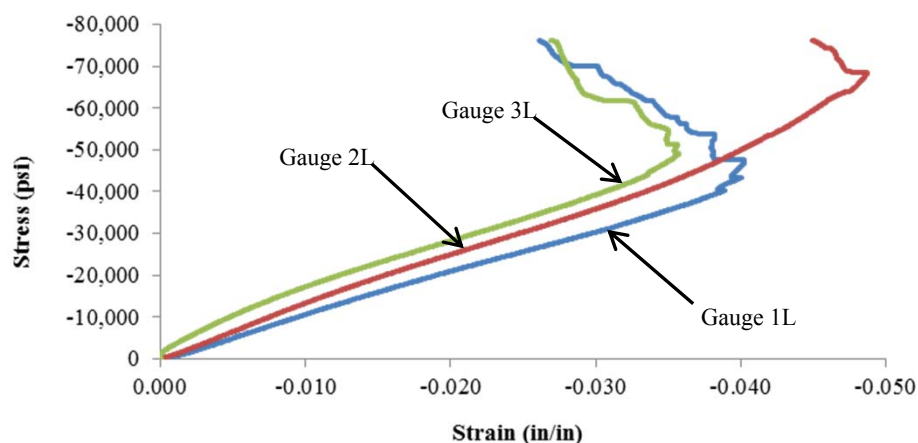
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.03720 | -0.01422 | 993,981 |
| 2L | -0.03183 | -0.01140 | 1,117,935 |
| 3L | -0.02900 | -0.00835 | 1,106,038 |
| Average | | | 1,072,651 |

Stress-Strain Curve N40_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-N40-FY08**
 Test Date: 12/1/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 30,913 lbs
 Maximum Stress, SC_z : 55,006 psi
 Compressive Modulus, E_z : 1,125,664 psi
 Ultimate Strain, ϵ_z : 0.049 in/in

Measured Specimen Dimensions:

Length, L: 1.370 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,183 psi
 50% Max Load: 15,457 psi

PICTURE OF SPECIMEN PRE-TEST



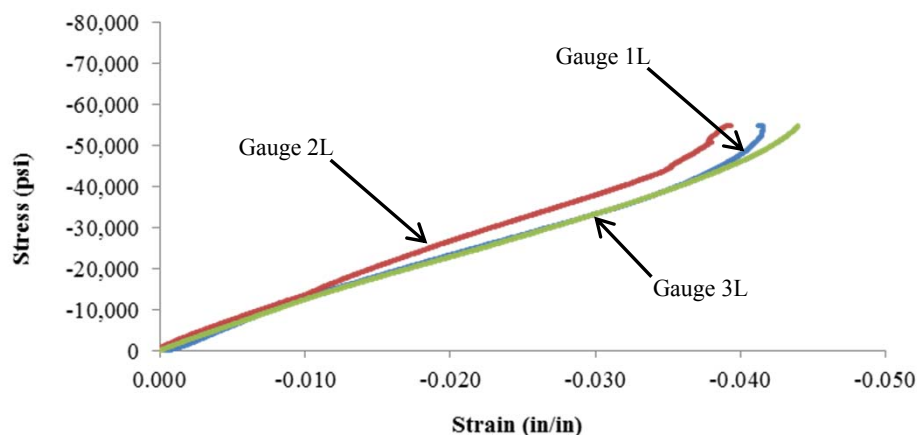
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02416 | -0.00846 | 1,051,172 |
| 2L | -0.02059 | -0.00772 | 1,282,366 |
| 3L | -0.02452 | -0.00870 | 1,043,453 |
| Average | | | 1,125,664 |

Stress-Strain Curve N40_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-N40-FY08**
 Test Date: 12/1/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

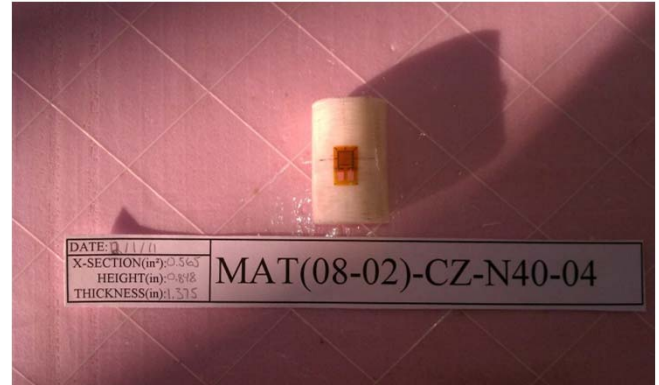
Average Material Properties:

Maximum Load, P_z : 34,257 lbs
 Maximum Stress, SC_z : 60,633 psi
 Compressive Modulus, E_z : 1,360,133 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

Measured Specimen Dimensions:

Length, L: 1.375 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,851 psi
 50% Max Load: 17,129 psi

PICTURE OF SPECIMEN PRE-TEST



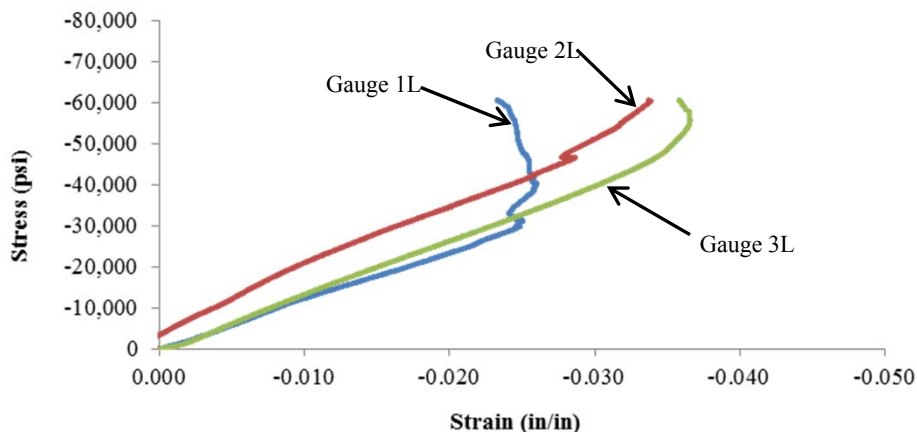
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02467 | -0.00981 | 1,223,901 |
| 2L | -0.01664 | -0.00497 | 1,558,306 |
| 3L | -0.02318 | -0.00917 | 1,298,191 |
| Average | | | 1,360,133 |

Stress-Strain Curve N40_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-05-N40-FY08**
 Test Date: 12/1/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 33,196 lbs
 Maximum Stress, SC_z : 59,173 psi
 Compressive Modulus, E_z : 1,168,644 psi
 Ultimate Strain, ϵ_z : 0.051 in/in

Measured Specimen Dimensions:

Length, L: 1.357 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,639 psi
 50% Max Load: 16,598 psi

PICTURE OF SPECIMEN PRE-TEST



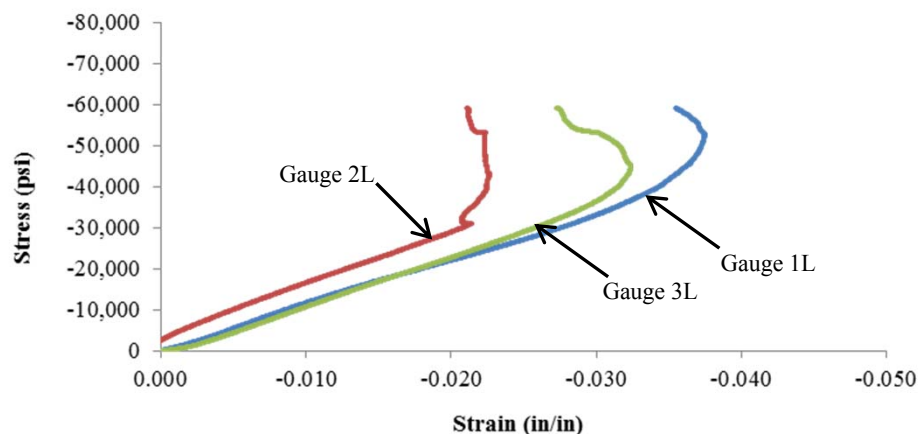
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02716 | -0.01006 | 1,037,951 |
| 2L | -0.02043 | -0.00625 | 1,251,766 |
| 3L | -0.02543 | -0.01083 | 1,216,216 |
| Average | | | 1,168,644 |

Stress-Strain Curve N40_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

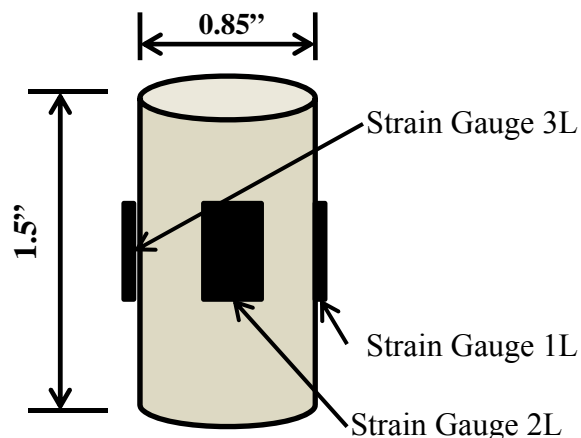
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CZ-70-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 31,465 lbs
 Compressive Strength, SC_z : 56,040 psi
 Compressive Modulus, E_z : 1,028,310 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT2-CZ-01-70-FY08 | 30,792 | 54,790 | 1,070,446 | 0.052 | Rupture |
| MAT2-CZ-02-70-FY08 | 33,256 | 59,706 | 948,550 | 0.064 | Rupture |
| MAT2-CZ-03-70-FY08 | 31,353 | 55,689 | 920,287 | 0.061 | Rupture |
| MAT2-CZ-04-70-FY08 | 32,739 | 58,359 | 1,015,454 | 0.059 | Rupture |
| MAT2-CZ-05-70-FY08 | 29,186 | 51,656 | 1,186,815 | 0.045 | Rupture |
| Average | 31,465 | 56,040 | 1,028,310 | 0.056 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Facing Researchers****Notes:**

- 1) Reference C-80 to C-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-70-FY08**
 Test Date: 11/22/11
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 30,792 lbs
 Maximum Stress, SC_z : 54,790 psi
 Compressive Modulus, E_z : 1,070,446 psi
 Ultimate Strain, ϵ_z : 0.052 in/in

Measured Specimen Dimensions:

Length, L: 1.363 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,158 psi
 50% Max Load: 15,396 psi

PICTURE OF SPECIMEN PRE-TEST



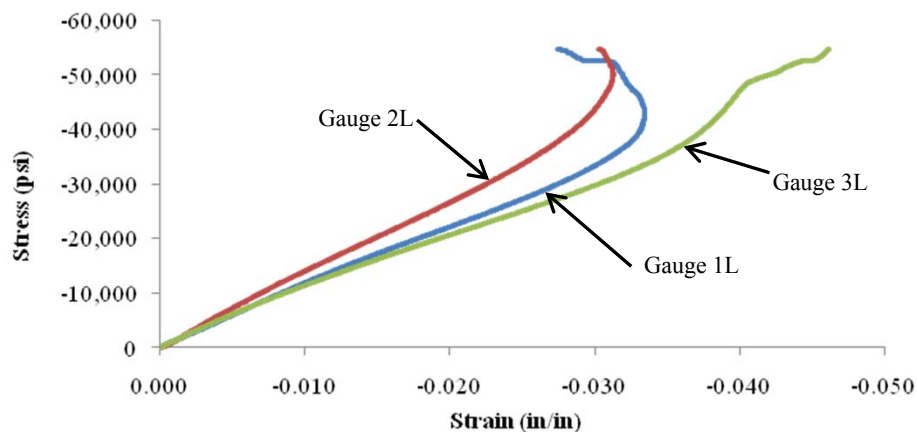
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02513 | -0.00917 | 1,029,827 |
| 2L | -0.02058 | -0.00763 | 1,269,590 |
| 3L | -0.02756 | -0.00953 | 911,920 |
| Average | | | 1,070,446 |

Stress-Strain Curve 70F_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-70-FY08**
 Test Date: 11/22/11
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 33,256 lbs
 Maximum Stress, SC_z : 59,706 psi
 Compressive Modulus, E_z : 948,550 psi
 Ultimate Strain, ϵ_z : 0.064 in/in

Measured Specimen Dimensions:

Length, L: 1.374 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,651 psi
 50% Max Load: 16,628 psi

PICTURE OF SPECIMEN PRE-TEST



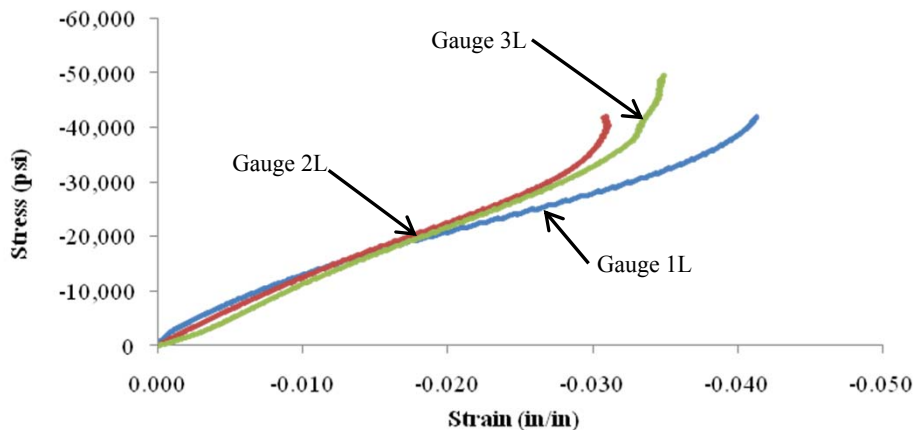
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.03226 | -0.00884 | 764,672 |
| 2L | -0.02675 | -0.00944 | 1,035,198 |
| 3L | -0.02765 | -0.01052 | 1,045,781 |
| Average | | | 948,550 |

Stress-Strain Curve 70F_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-70-FY08**
 Test Date: 11/22/11
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 31,353 lbs
 Maximum Stress, SC_z : 55,689 psi
 Compressive Modulus, E_z : 920,287 psi
 Ultimate Strain, ϵ_z : 0.061 in/in

Measured Specimen Dimensions:

Length, L: 1.374 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,271 psi
 50% Max Load: 15,677 psi

PICTURE OF SPECIMEN PRE-TEST



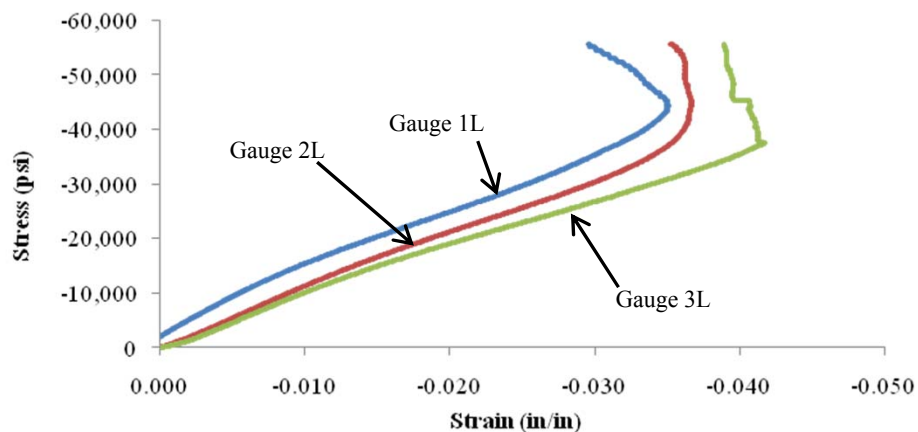
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.02315 | -0.00631 | 992,299 |
| 2L | -0.02739 | -0.00979 | 949,282 |
| 3L | -0.03133 | -0.01094 | 819,279 |
| Average | | | 920,287 |

Stress-Strain Curve 70F_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-70-FY08**
 Test Date: 11/22/11
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 32,739 lbs
 Maximum Stress, SC_z : 58,359 psi
 Compressive Modulus, E_z : 1,015,454 psi
 Ultimate Strain, ϵ_z : 0.059 in/in

Measured Specimen Dimensions:

Length, L: 1.360 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,548 psi
 50% Max Load: 16,370 psi

PICTURE OF SPECIMEN PRE-TEST



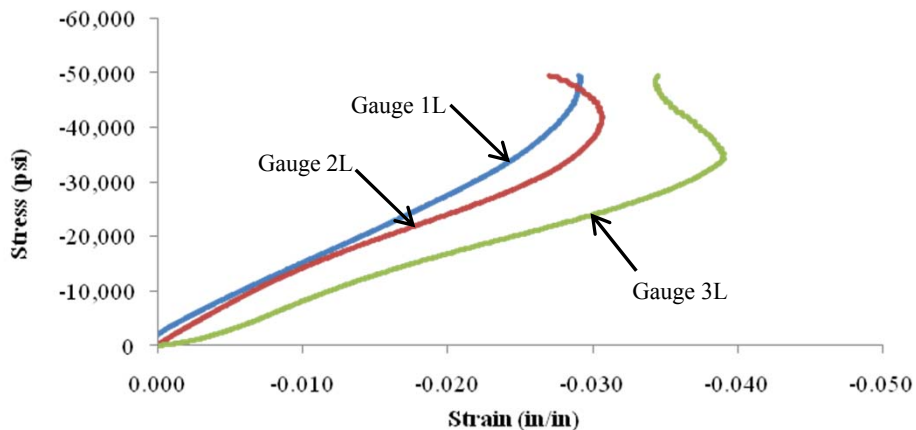
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02114 | -0.00699 | 1,237,454 |
| 2L | -0.02494 | -0.00778 | 1,020,797 |
| 3L | -0.03572 | -0.01350 | 788,051 |
| Average | | | 1,015,454 |

Stress-Strain Curve 70_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-05-70-FY08**
 Test Date: 11/22/11
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 29,186 lbs
 Maximum Stress, SC_z : 51,656 psi
 Compressive Modulus, E_z : 1,186,815 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

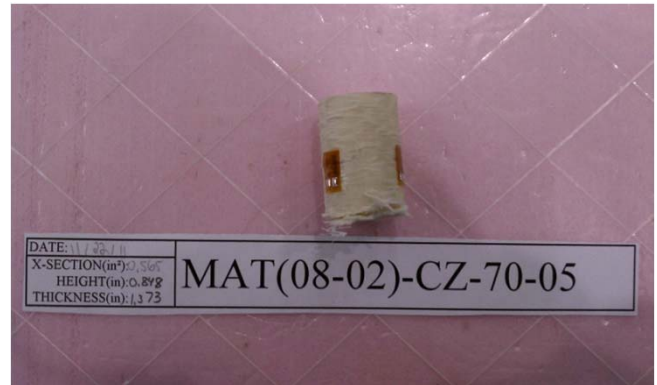
Measured Specimen Dimensions:

Length, L: 1.373 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,837 psi
 50% Max Load: 14,593 psi

PICTURE OF SPECIMEN PRE-TEST



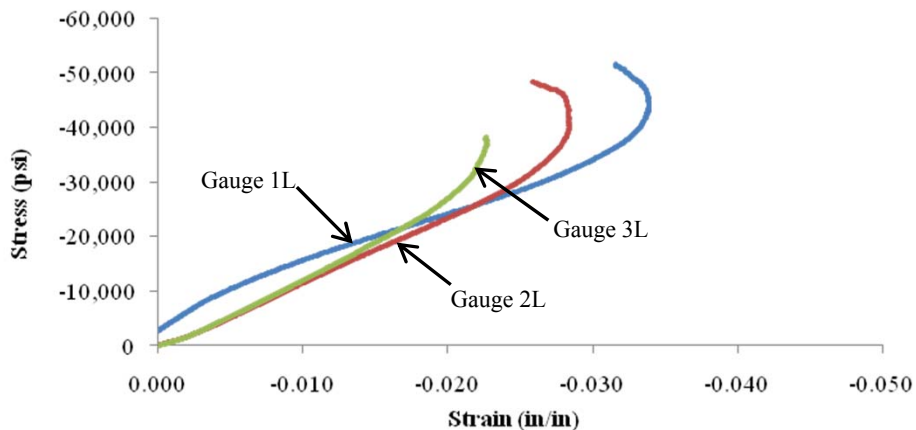
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02202 | -0.00492 | 906,395 |
| 2L | -0.02197 | -0.00909 | 1,202,453 |
| 3L | -0.01944 | -0.00876 | 1,451,597 |
| Average | | | 1,186,815 |

Stress-Strain Curve 70F_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

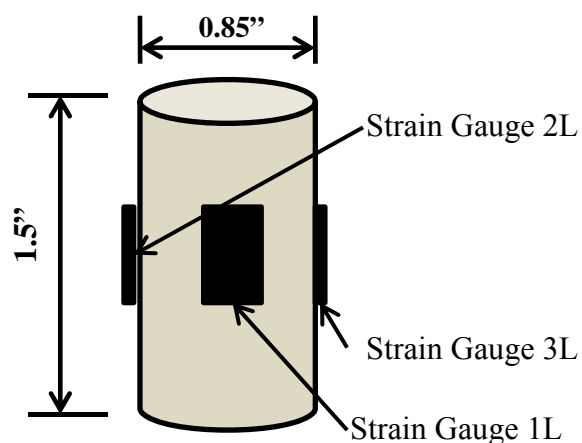
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CZ-140-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 26,028 lbs
 Compressive Strength, SC_z : 46,393 psi
 Compressive Modulus, E_z : 969,253 psi
 Ultimate Strain, ϵ_z : 0.049 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT2-CZ-01-140-FY08 | 26,315 | 47,414 | 1,005,992 | 0.050 | Rupture |
| MAT2-CZ-02-140-FY08 | 28,152 | 49,826 | 1,061,887 | 0.047 | Rupture |
| MAT2-CZ-03-140-FY08 | 25,237 | 44,905 | 1,007,978 | 0.045 | Rupture |
| MAT2-CZ-04-140-FY08 | 26,166 | 46,559 | 999,011 | 0.047 | Rupture |
| MAT2-CZ-05-140-FY08 | 24,268 | 43,259 | 771,399 | 0.056 | Rupture |
| Average | 26,028 | 46,393 | 969,253 | 0.049 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

Facing Researchers

Notes:

- 1) Reference C-86 to C-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-140-FY08**
 Test Date: 11/22/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 26,315 lbs
 Maximum Stress, SC_z : 47,414 psi
 Compressive Modulus, E_z : 1,005,992 psi
 Ultimate Strain, ϵ_z : 0.050 in/in

Measured Specimen Dimensions:

Length, L: 1.368 in
 Diameter, D: 0.841 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,631 psi
 30% Max Load: 7,894 psi

PICTURE OF SPECIMEN PRE-TEST



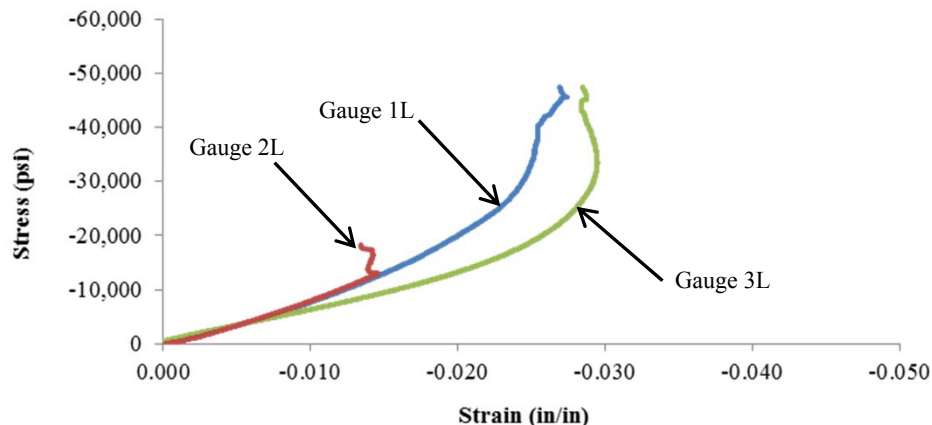
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 30% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01599 | -0.00677 | 1,027,945 |
| 2L | -0.01394 | -0.00664 | 1,298,259 |
| 3L | -0.02105 | -0.00735 | 691,773 |
| Average | | | 1,260,247 |

Stress-Strain Curve 140_01_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 30% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-140-FY08**
 Test Date: 11/22/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 28,152 lbs
 Maximum Stress, SC_z : 49,826 psi
 Compressive Modulus, E_z : 1,061,887 psi
 Ultimate Strain, ϵ_z : 0.047 in/in

Measured Specimen Dimensions:

Length, L: 1.360 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,815 psi
 30% Max Load: 8,446 psi

PICTURE OF SPECIMEN PRE-TEST



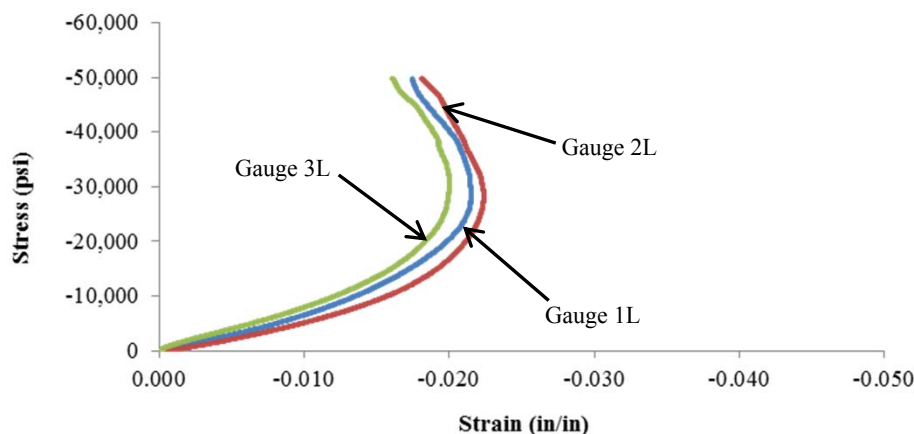
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 30% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01720 | -0.00800 | 1,083,817 |
| 2L | -0.01912 | -0.00976 | 1,064,781 |
| 3L | -0.01592 | -0.00631 | 1,037,063 |
| Average | | | 1,061,887 |

Stress-Strain Curve 140_02_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 30% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-140-FY08**
 Test Date: 11/23/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 25,237 lbs
 Maximum Stress, SC_z : 44,905 psi
 Compressive Modulus, E_z : 1,007,978 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

Measured Specimen Dimensions:

Length, L: 1.371 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,524 psi
 30% Max Load: 7,571 psi

PICTURE OF SPECIMEN PRE-TEST



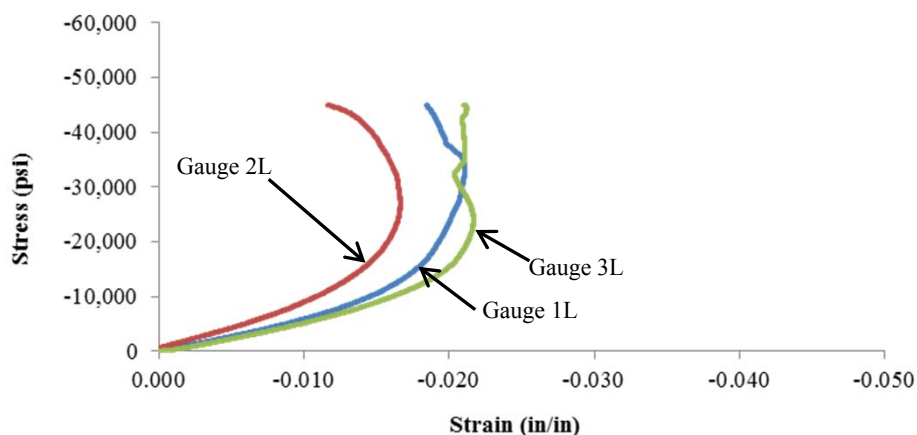
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 30% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01693 | -0.00790 | 995,139 |
| 2L | -0.01316 | -0.00524 | 1,133,614 |
| 3L | -0.01894 | -0.00890 | 895,182 |
| Average | | | 1,007,978 |

Stress-Strain Curve 140_03_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 30% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-140-FY08**
 Test Date: 11/28/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 26,166 lbs
 Maximum Stress, SC_z : 46,559 psi
 Compressive Modulus, E_z : 999,011 psi
 Ultimate Strain, ϵ_z : 0.047 in/in

Measured Specimen Dimensions:

Length, L: 1.357 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,617 psi
 30% Max Load: 7,850 psi

PICTURE OF SPECIMEN PRE-TEST



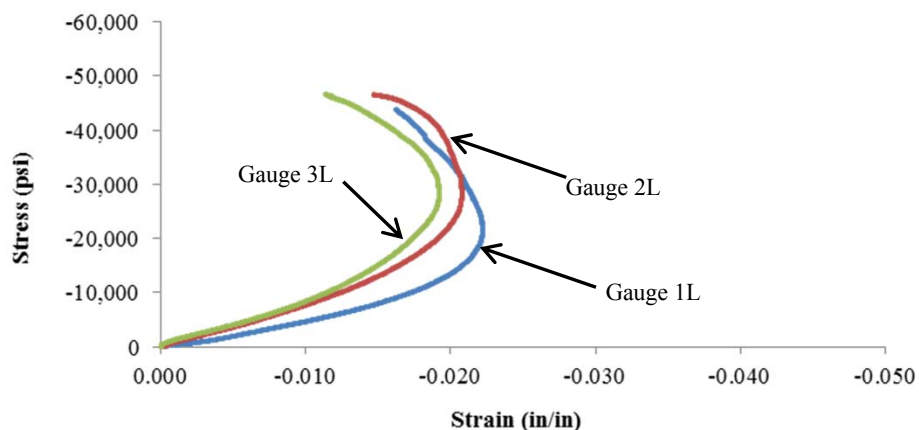
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 30% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02030 | -0.01001 | 905,262 |
| 2L | -0.01571 | -0.00638 | 997,817 |
| 3L | -0.01433 | -0.00582 | 1,093,954 |
| Average | | | 999,011 |

Stress-Strain Curve 140_04_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 30% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-05-140-FY08**
 Test Date: 11/28/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 24,268 lbs
 Maximum Stress, SC_z : 43,259 psi
 Compressive Modulus, E_z : 771,399 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured Specimen Dimensions:

Length, L: 1.371 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,427 psi
 30% Max Load: 7,281 psi

PICTURE OF SPECIMEN PRE-TEST



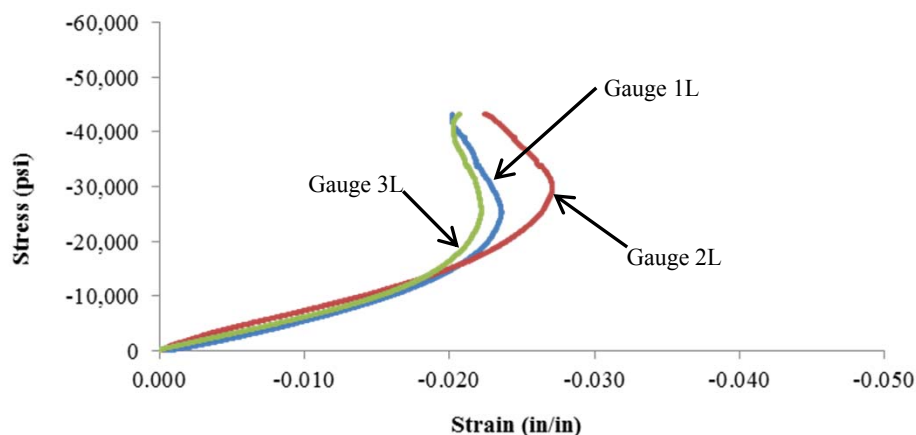
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 30% Max Load ϵ_z , (in/in) | Strain @ 10% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.01869 | -0.00829 | 832,143 |
| 2L | -0.01770 | -0.00511 | 687,330 |
| 3L | -0.01783 | -0.00694 | 794,222 |
| Average | | | 771,399 |

Stress-Strain Curve 140_05_(08-02)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 30% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

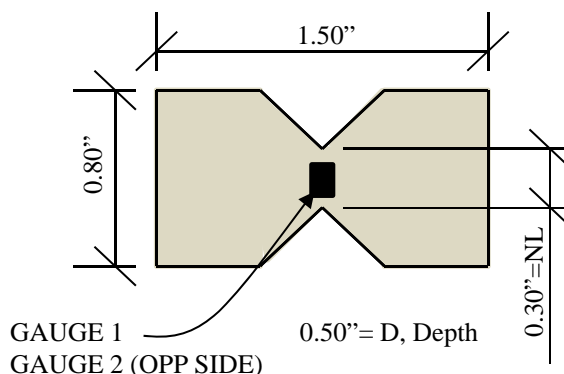
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-SXZ-N40-FY08
Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
Nominal Temperature: -40°F
Properties Measured: G_{xz} , S_{xz}
Average Material Properties (5 Specimens):
Ultimate Load, P_{max} : 767 lbs
Shear Strength, S_{xz} : 5,360 psi
Shear Modulus, G_{xz} : 394,355 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|-------------------------------|--------------------------------|-------------------------------|--------------|
| MAT2-SXZ-01-N40-FY08 | 759 | 5,300 | 369,221 | Shear |
| MAT2-SXZ-02-N40-FY08 | 769 | 5,387 | 392,608 | Shear |
| MAT2-SXZ-03-N40-FY08 | 750 | 5,213 | 426,812 | Shear |
| MAT2-SXZ-04-N40-FY08 | 769 | 5,395 | 386,704 | Shear |
| MAT2-SXZ-05-N40-FY08 | 789 | 5,504 | 396,428 | Shear |
| Average | 767 | 5,360 | 394,355 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-92 to C-96
- 2) Showing relevant data from all five specimens tested
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-01-N40-FY08
 Test Date: 8/7/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

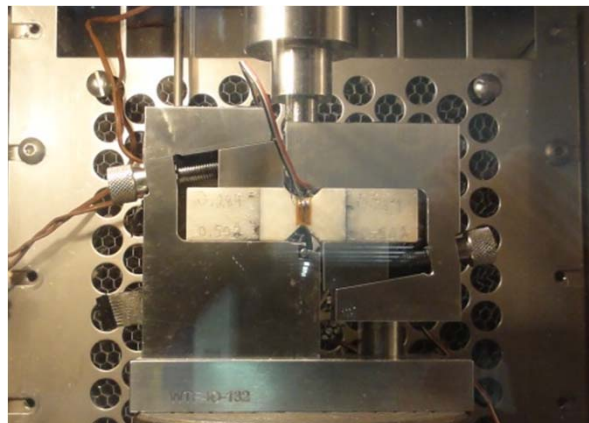
Average Material Properties:

Ultimate Load, P_{max} : 759 lbs
 Shear Strength, S_{xz} : 5,300 psi
 Shear Modulus, G_{xz} : 369,221 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 380 lbs
 20% Max Load: 152 lbs

PICTURE OF SPECIMEN PRE-TEST

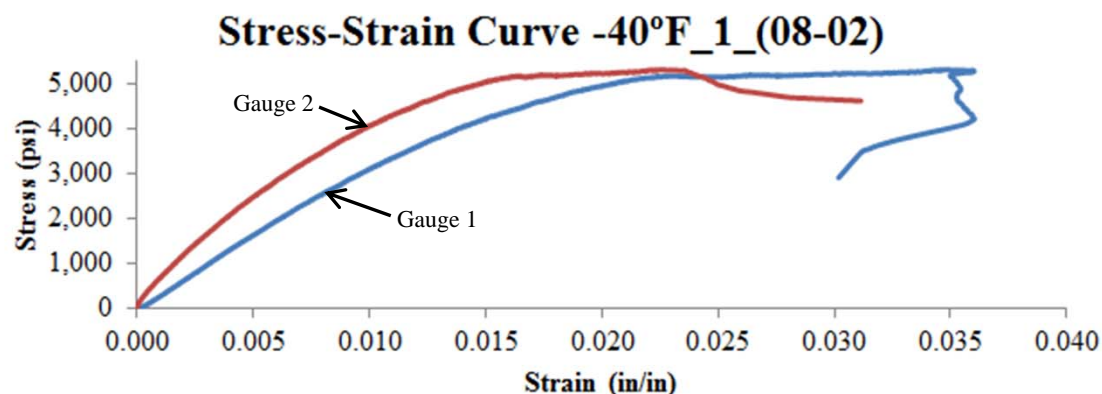


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0083 | 0.0033 | 313,059 |
| 2 | 0.0055 | 0.0017 | 425,382 |
| Average | | | 369,221 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-02-N40-FY08
 Test Date: 8/8/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

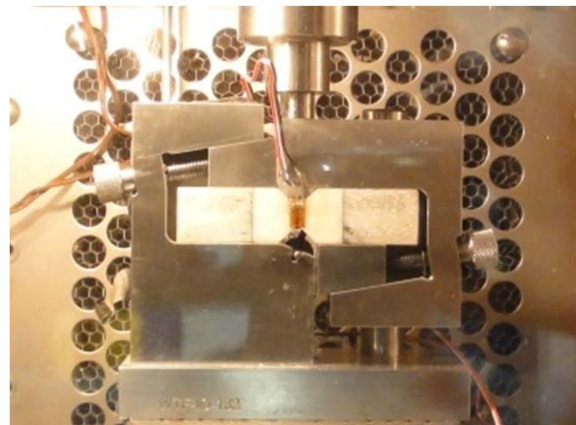
Average Material Properties:

Ultimate Load, P_{max} : 769 lbs
 Shear Strength, S_{xz} : 5,387 psi
 Shear Modulus, G_{xz} : 392,608 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.285 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 385 lbs
 20% Max Load: 154 lbs

PICTURE OF SPECIMEN PRE-TEST

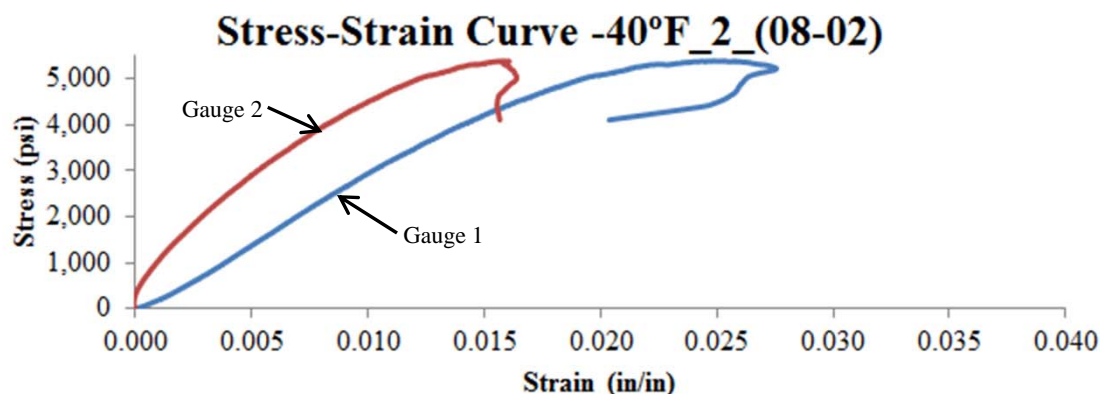


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0092 | 0.0041 | 316,856 |
| 2 | 0.0045 | 0.0010 | 468,360 |
| Average | | | 392,608 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-03-N40-FY08
 Test Date: 8/8/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

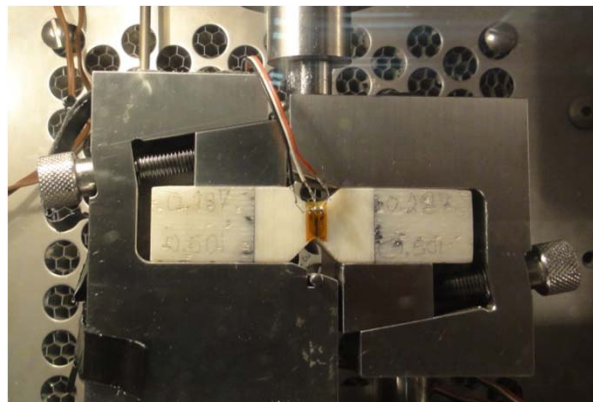
Average Material Properties:

Ultimate Load, P_{max} : 750 lbs
 Shear Strength, S_{xz} : 5,213 psi
 Shear Modulus, G_{xz} : 426,812 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.287 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 375 lbs
 20% Max Load: 150 lbs

PICTURE OF SPECIMEN PRE-TEST

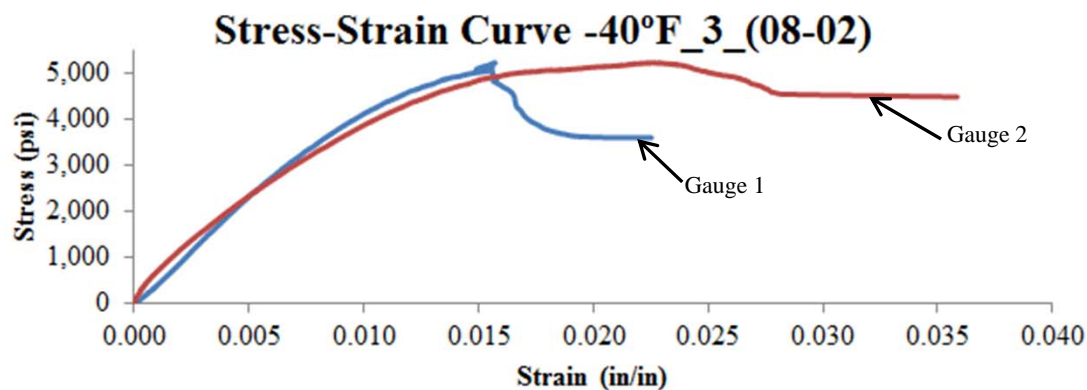


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0057 | 0.0023 | 468,137 |
| 2 | 0.0058 | 0.0017 | 385,488 |
| Average | | | 426,812 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-04-N40-FY08
 Test Date: 8/8/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

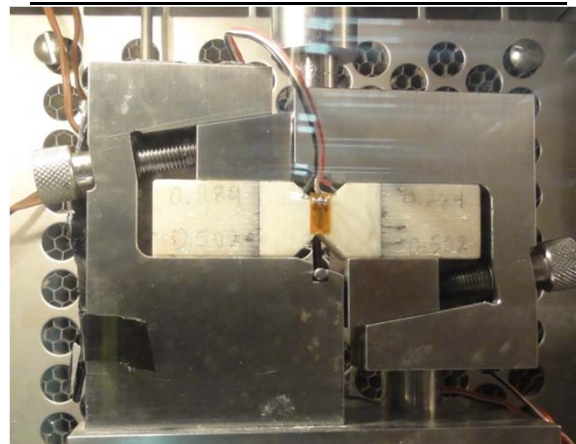
Average Material Properties:

Ultimate Load, P_{max} : 769 lbs
 Shear Strength, S_{xz} : 5,395 psi
 Shear Modulus, G_{xz} : 386,704 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.284 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 385 lbs
 20% Max Load: 154 lbs

PICTURE OF SPECIMEN PRE-TEST

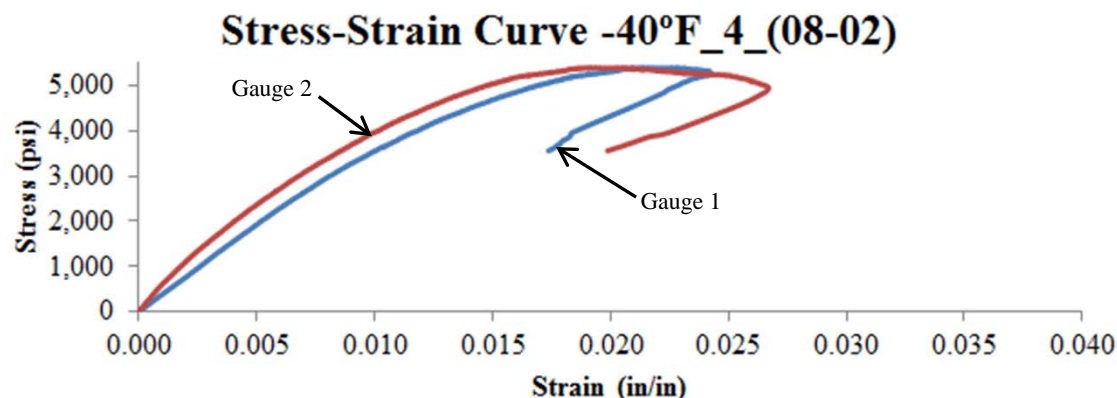


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0072 | 0.0028 | 366,935 |
| 2 | 0.0059 | 0.0019 | 406,474 |
| Average | | | 386,704 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-05-N40-FY08
 Test Date: 8/8/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

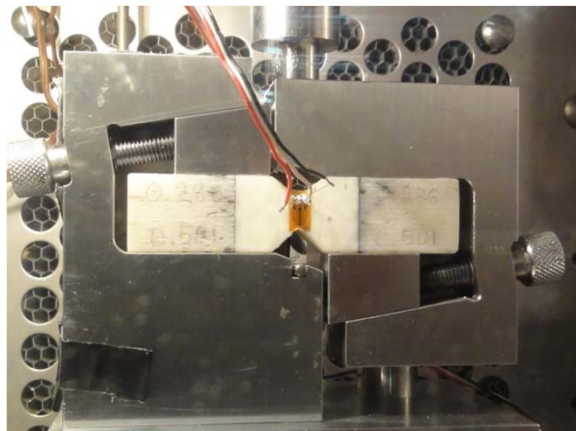
Average Material Properties:

Ultimate Load, P_{max} : 789 lbs
 Shear Strength, S_{xz} : 5,504 psi
 Shear Modulus, G_{xz} : 396,428 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 394 lbs
 20% Max Load: 158 lbs

PICTURE OF SPECIMEN PRE-TEST

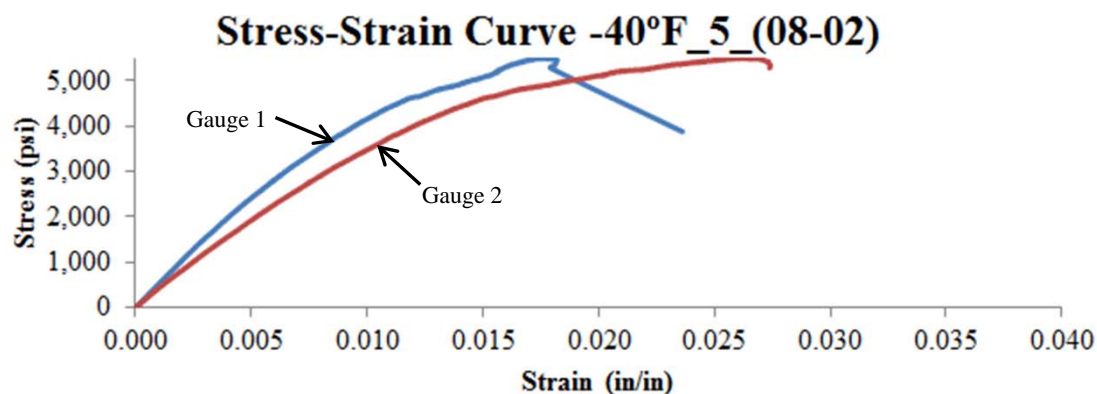


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0058 | 0.0021 | 445,224 |
| 2 | 0.0075 | 0.0027 | 347,632 |
| Average | | | 396,428 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

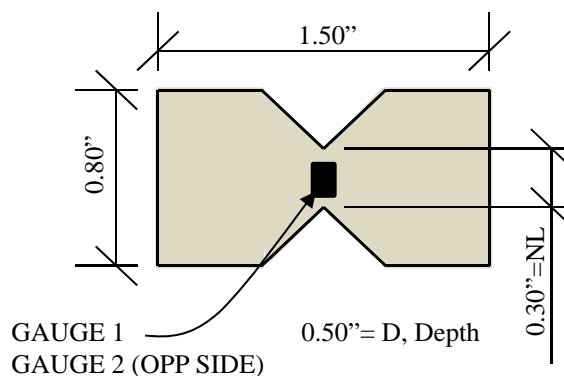
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXZ-70-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **439** **lbs**
 Shear Strength, S_{xz} : **3,064** **psi**
 Shear Modulus, G_{xz} : **272,697** **psi**

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT2-SXZ-01-70-FY08 | 440 | 3,073 | 271,111 | Shear |
| MAT2-SXZ-02-70-FY08 | 422 | 2,936 | 267,070 | Shear |
| MAT2-SXZ-03-70-FY08 | 438 | 3,059 | 247,310 | Shear |
| MAT2-SXZ-04-70-FY08 | 444 | 3,092 | 295,042 | Shear |
| MAT2-SXZ-05-70-FY08 | 449 | 3,159 | 282,952 | Shear |
| Average | 439 | 3,064 | 272,697 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-98 to C-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-01-70-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/11
 Properties Measured: S_{xz} , G_{xz}

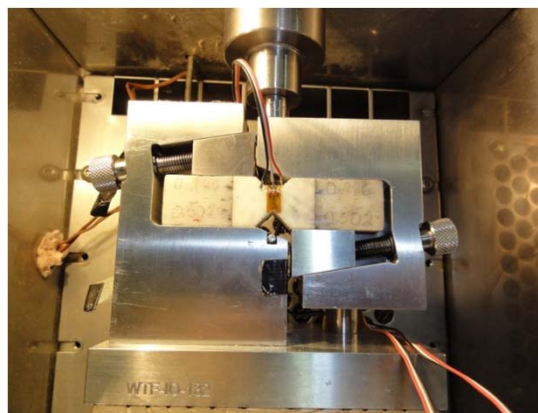
Average Material Properties:

Ultimate Load, P_{max} : 440 lbs
 Shear Strength, S_{xz} : 3,073 psi
 Shear Modulus, G_{xz} : 271,111 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.285 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 220 lbs
 20% Max Load: 88 lbs

PICTURE OF SPECIMEN PRE-TEST

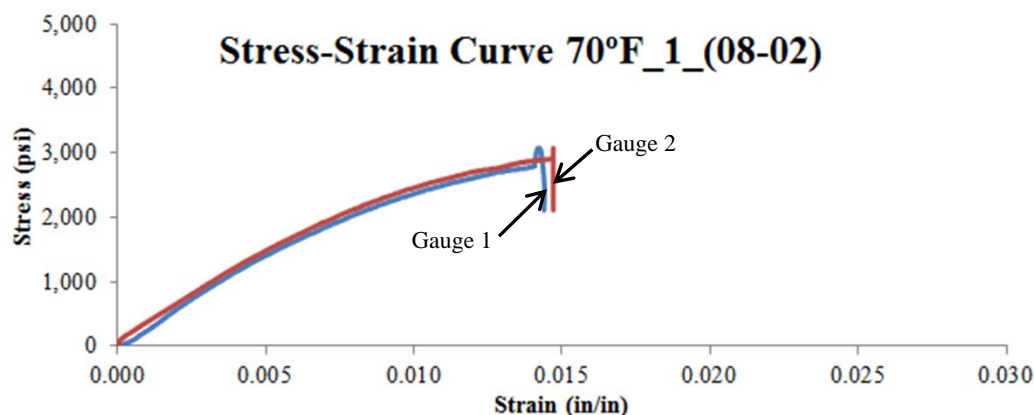


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0056 | 0.0021 | 269,501 |
| 2 | 0.0052 | 0.0018 | 272,721 |
| Average | | | 271,111 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-02-70-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 422 lbs
 Shear Strength, S_{xz} : 2,936 psi
 Shear Modulus, G_{xz} : 267,070 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 211 lbs
 20% Max Load: 84 lbs

PICTURE OF SPECIMEN PRE-TEST

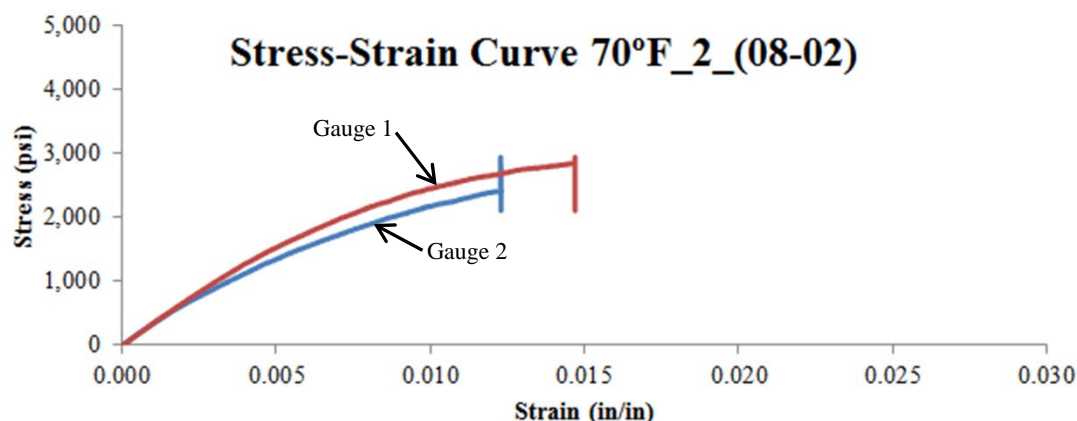


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0056 | 0.0018 | 237,160 |
| 2 | 0.0047 | 0.0018 | 296,979 |
| Average | | | 267,070 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-03-70-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/11
 Properties Measured: S_{xz} , G_{xz}

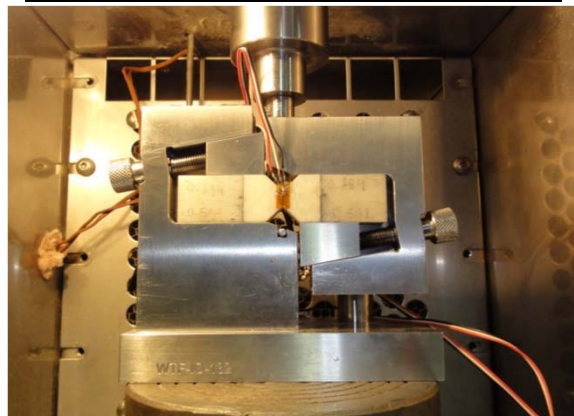
Average Material Properties:

Ultimate Load, P_{max} : 438 lbs
 Shear Strength, S_{xz} : 3,059 psi
 Shear Modulus, G_{xz} : 247,310 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 219 lbs
 20% Max Load: 88 lbs

PICTURE OF SPECIMEN PRE-TEST

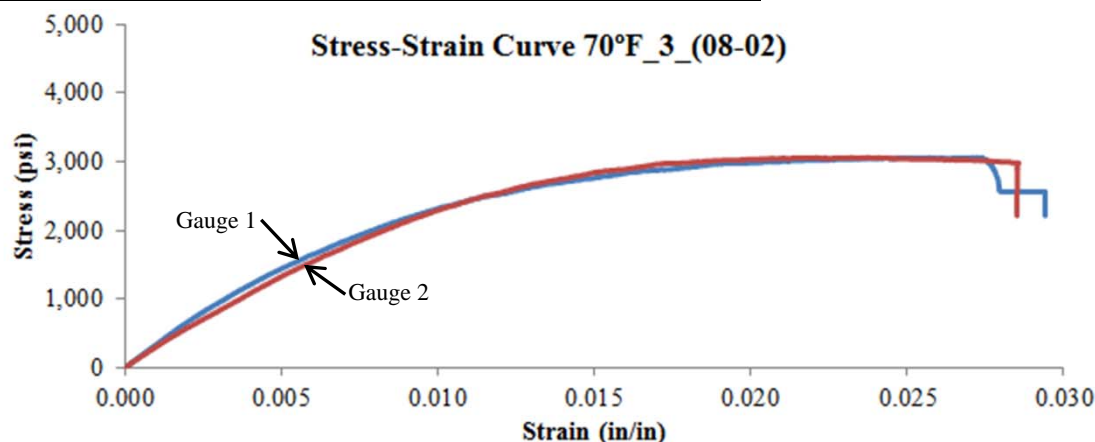


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0054 | 0.0018 | 253,886 |
| 2 | 0.0059 | 0.0021 | 240,734 |
| Average | | | 247,310 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-04-70-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/11
 Properties Measured: S_{xz} , G_{xz}

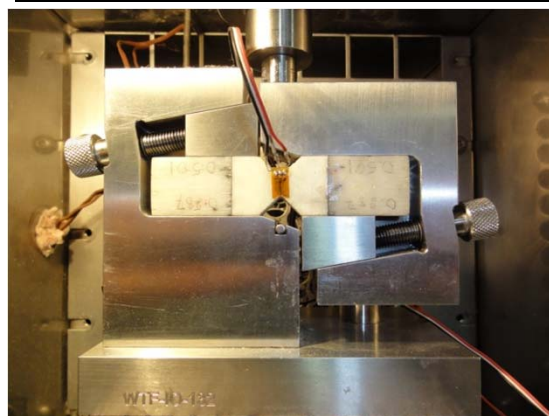
Average Material Properties:

Ultimate Load, P_{max} : 444 lbs
 Shear Strength, S_{xz} : 3,092 psi
 Shear Modulus, G_{xz} : 295,042 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 222 lbs
 20% Max Load: 89 lbs

PICTURE OF SPECIMEN PRE-TEST

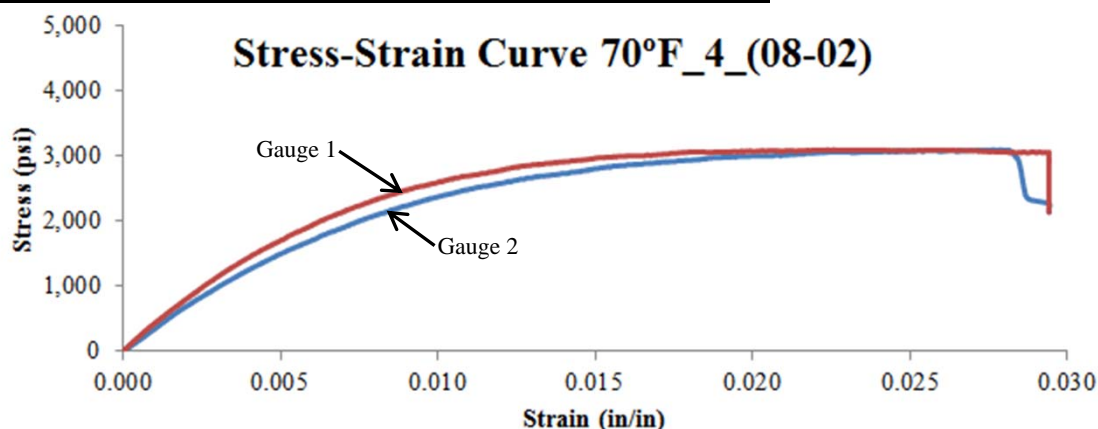


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0018 | 268,266 |
| 2 | 0.0044 | 0.0015 | 321,819 |
| Average | | | 295,042 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-05-70-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/11
 Properties Measured: S_{xz} , G_{xz}

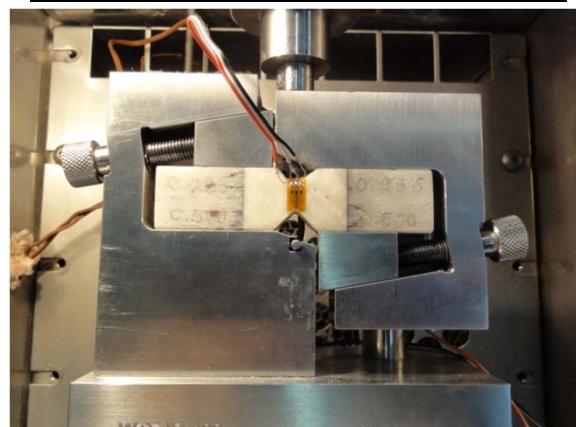
Average Material Properties:

Ultimate Load, P_{max} : 449 lbs
 Shear Strength, S_{xz} : 3,159 psi
 Shear Modulus, G_{xz} : 282,952 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.284 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 225 lbs
 20% Max Load: 90 lbs

PICTURE OF SPECIMEN PRE-TEST

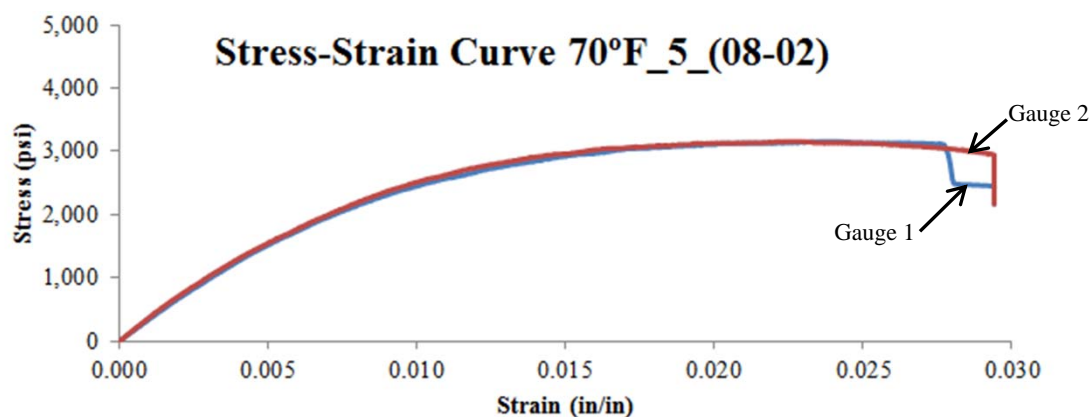


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0019 | 282,308 |
| 2 | 0.0051 | 0.0017 | 283,597 |
| Average | | | 282,952 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

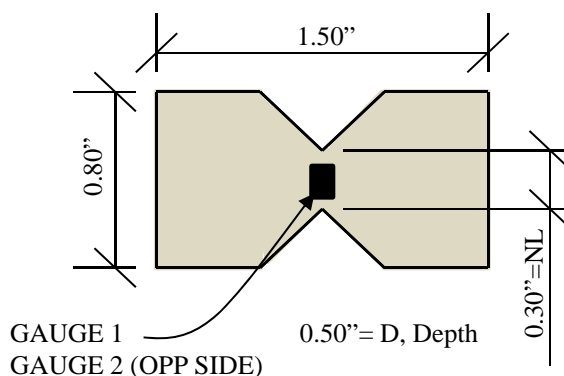
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-SXZ-140-FY08
Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
Nominal Temperature: 140°F
Properties Measured: G_{xz} , S_{xz}
Average Material Properties (5 Specimens):
Ultimate Load, P_{max} : 151 lbs
Shear Strength, S_{xz} : 1,053 psi
Shear Modulus, G_{xz} : 20,012 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT2-SXZ-01-140-FY08 | 155 | 1,078 | 24,243 | Shear |
| MAT2-SXZ-02-140-FY08 | 141 | 984 | 20,137 | Shear |
| MAT2-SXZ-03-140-FY08 | 155 | 1,087 | 15,657 | Shear |
| MAT2-SXZ-04-140-FY08 | 161 | 1,123 | 20,826 | Shear |
| MAT2-SXZ-05-140-FY08 | 144 | 993 | 19,198 | Shear |
| Average | 151 | 1,053 | 20,012 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets C-104 to C-108
- 2) Six specimens tested. Showing five with most relevant data
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-01-140-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

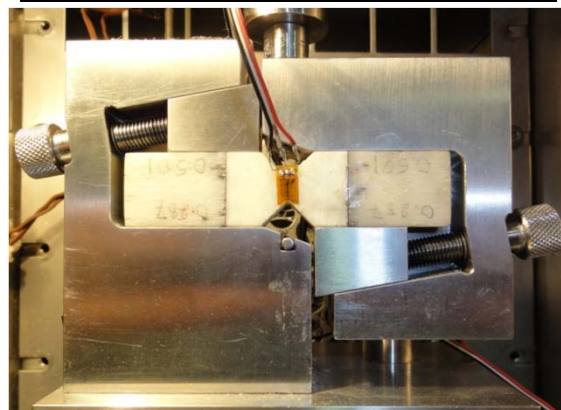
Average Material Properties:

Ultimate Load, P_{max} : 155 lbs
 Shear Strength, S_{xz} : 1,078 psi
 Shear Modulus, G_{xz} : 24,243 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.287 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 77 lbs
 20% Max Load: 31 lbs

PICTURE OF SPECIMEN PRE-TEST

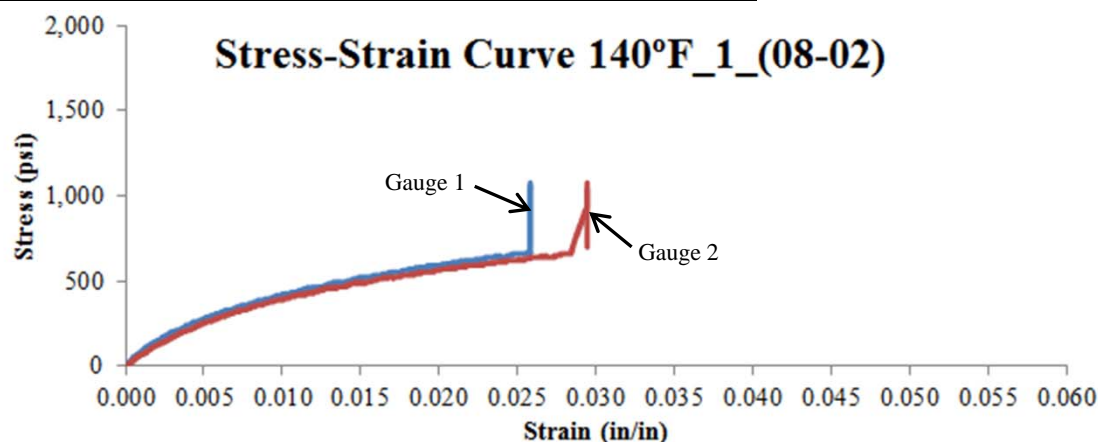


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0163 | 0.0035 | 25,267 |
| 2 | 0.0181 | 0.0042 | 23,218 |
| Average | | | 24,243 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-02-140-FY08
 Test Date: 8/1/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

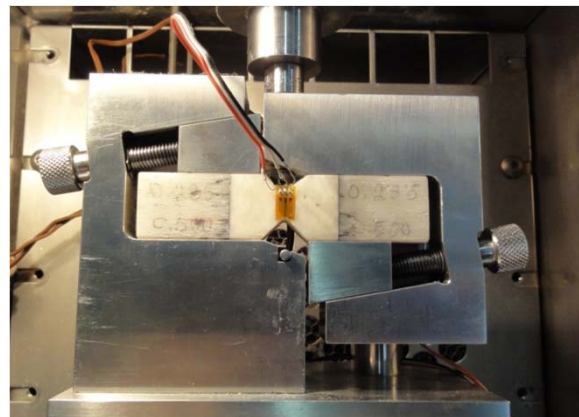
Average Material Properties:

Ultimate Load, P_{max} : 141 lbs
 Shear Strength, S_{xz} : 984 psi
 Shear Modulus, G_{xz} : 20,137 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 70 lbs
 20% Max Load: 28 lbs

PICTURE OF SPECIMEN PRE-TEST

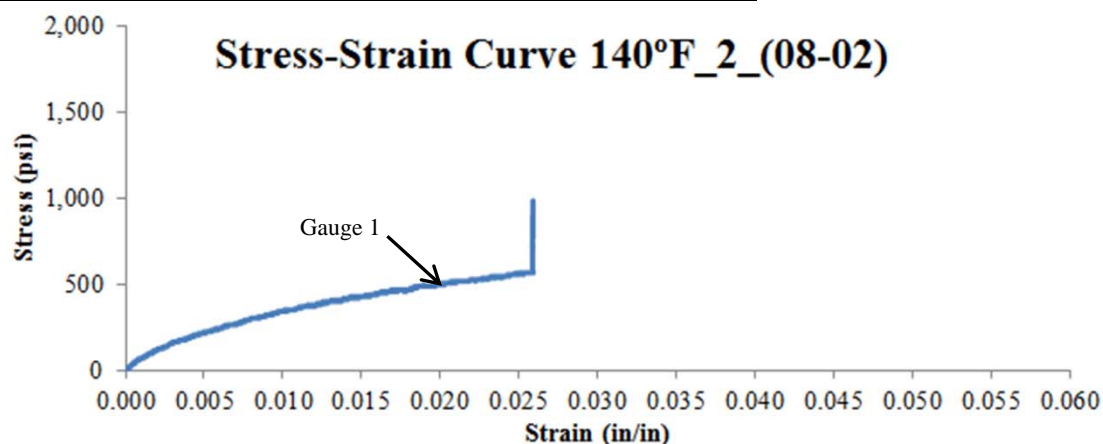


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0189 | 0.0042 | 20,137 |
| 2 | Lost Gauge | | |
| Average | | | 20,137 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-03-140-FY08
 Test Date: 8/2/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

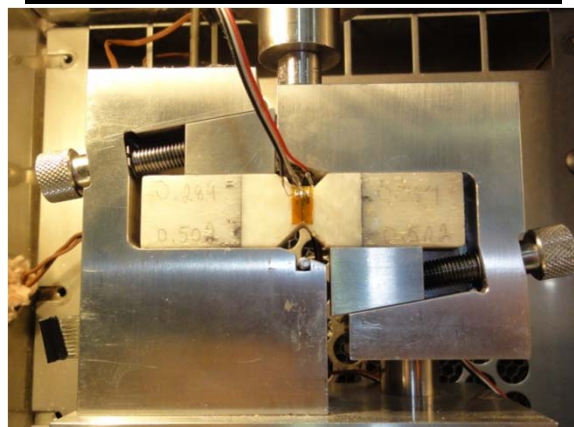
Average Material Properties:

Ultimate Load, P_{max} : 155 lbs
 Shear Strength, S_{xz} : 1,087 psi
 Shear Modulus, G_{xz} : 15,657 psi

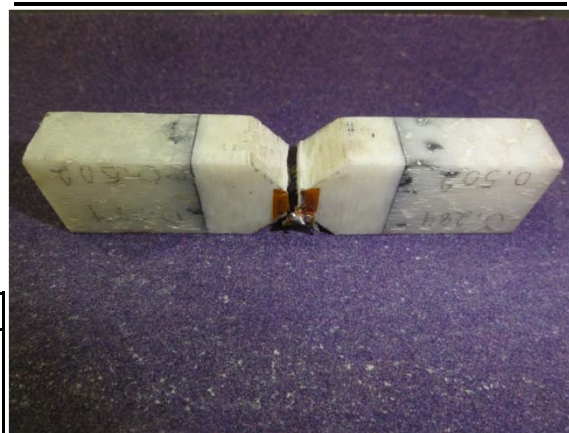
Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.284 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 77 lbs
 20% Max Load: 31 lbs

PICTURE OF SPECIMEN PRE-TEST

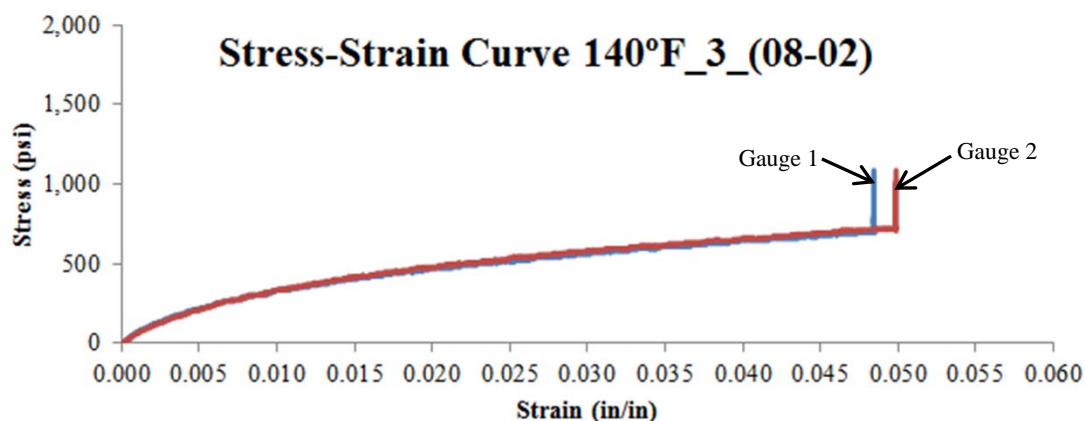


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0268 | 0.0050 | 15,010 |
| 2 | 0.0252 | 0.0052 | 16,305 |
| Average | | | 15,657 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-04-140-FY08**
 Test Date: 8/2/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

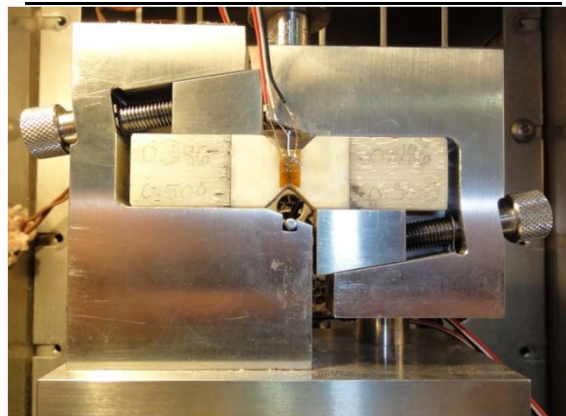
Average Material Properties:

Ultimate Load, P_{max} : 161 lbs
 Shear Strength, S_{xz} : 1,123 psi
 Shear Modulus, G_{xz} : 20,826 psi

Measured Specimen Dimensions:

Depth, D: 0.500 in
 Notch Length, NL: 0.286 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 80 lbs
 20% Max Load: 32 lbs

PICTURE OF SPECIMEN PRE-TEST

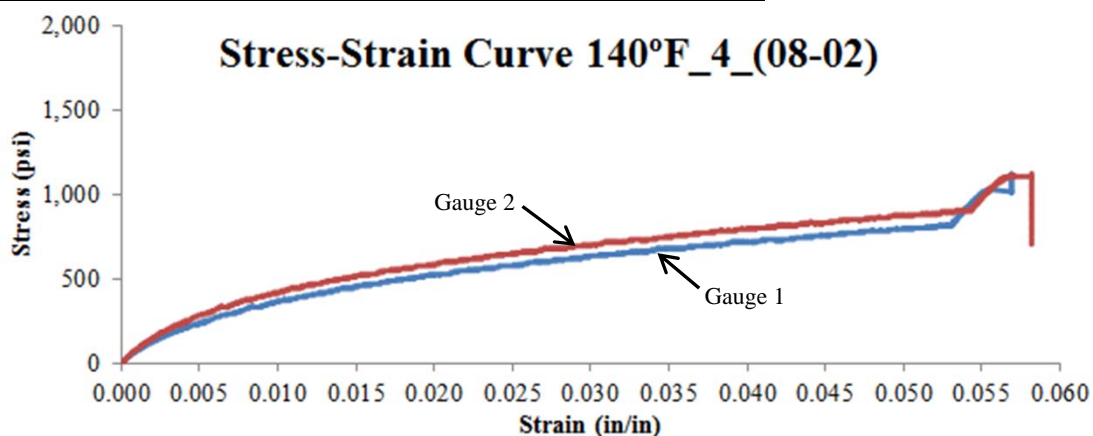


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0231 | 0.0047 | 18,261 |
| 2 | 0.0180 | 0.0036 | 23,391 |
| Average | | | 20,826 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXZ-05-140-FY08
 Test Date: 8/2/12
 Specimen Received: 4/23/12
 Properties Measured: S_{xz} , G_{xz}

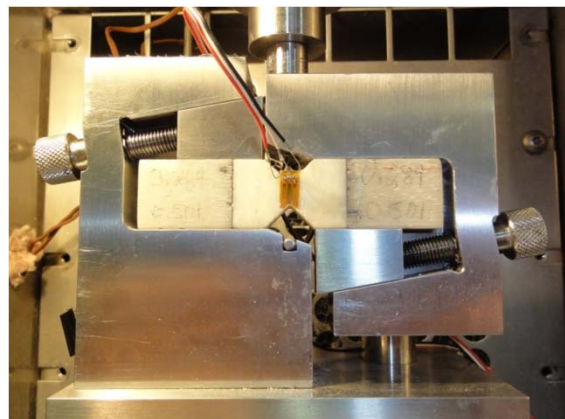
Average Material Properties:

Ultimate Load, P_{max} : 144 lbs
 Shear Strength, S_{xz} : 993 psi
 Shear Modulus, G_{xz} : 19,198 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.289 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 72 lbs
 20% Max Load: 29 lbs

PICTURE OF SPECIMEN PRE-TEST

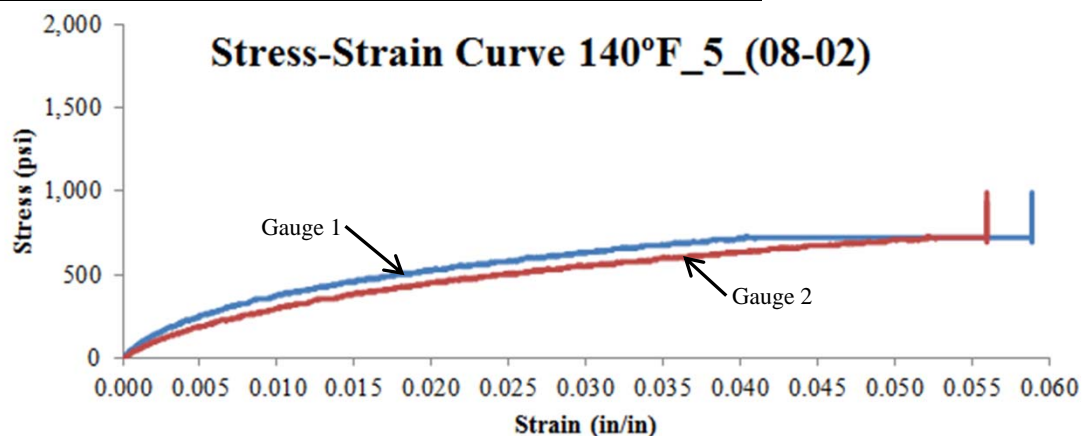


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0173 | 0.0037 | 21,884 |
| 2 | 0.0239 | 0.0058 | 16,512 |
| Average | | | 19,198 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-OP-N40-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: ν_{xz}
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1127
 Maximum Load, P_z : 4,955 lbs

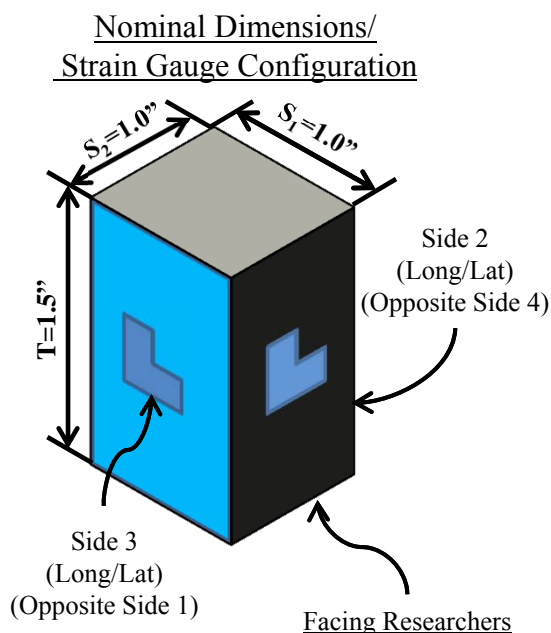
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT2-OP-1-N40-FY08 | 4,955 | 0.1143 | Rupture |
| 2 | MAT2-OP-2-N40-FY08 | 4,960 | 0.1599 | Bondline |
| 3 | MAT2-OP-3-N40-FY08 | 4,950 | 0.0856 | Bondline |
| 4 | MAT2-OP-4-N40-FY08 | 4,960 | 0.1156 | Rupture |
| 5 | MAT2-OP-5-N40-FY08 | 4,950 | 0.0880 | Rupture |
| Average | | 4,955 | 0.1127 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) Reference C-110 thru C-114 for individual specimen data.
- 2) Group of 5 specimens tested with representative data to report.
- 3) Max Load is based on MAT2-TX-N40-FY08 strength data.
- 4) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.
- 5) Bondline refers to failure at material and end tab bond interface.



TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-1-N40-FY08**
 Test Date: 8/9/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,955 lbs
 Poisson's Ratio, v_{xz} : 0.1143

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.999 in
 Side 2: 0.998 in

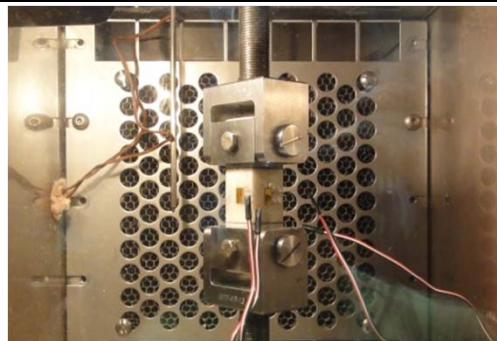
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,478 lbs

20% Max Load: 991 lbs

PICTURE OF SPECIMEN PRE-TEST

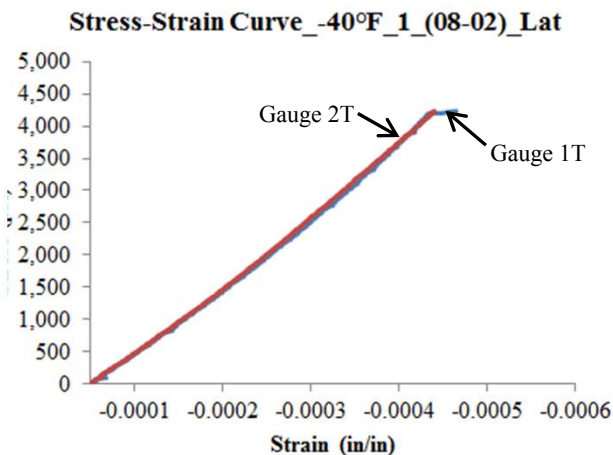
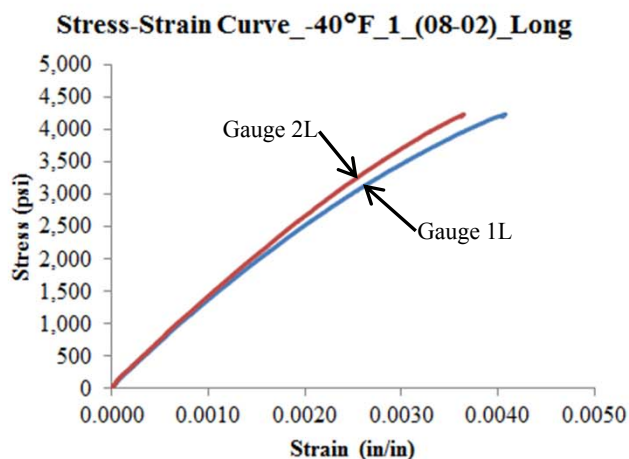


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001966 | 0.000698 | 1T | -0.000247 | -0.000106 | 0.1110 |
| 2L | 0.001845 | 0.000669 | 2T | -0.000242 | -0.000104 | 0.1175 |
| Average | | | | | | 0.1143 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-N40-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-2-N40-FY08**
 Test Date: 8/10/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

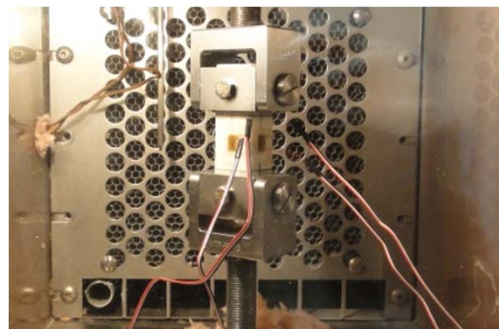
Average Material Properties:

Maximum Load, P_z : 4,960 lbs
 Poisson's Ratio, v_{xz} : 0.1599

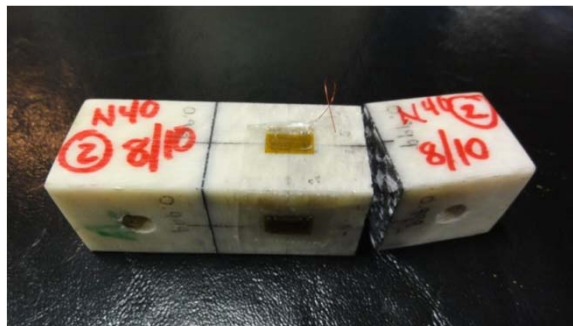
Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.999 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 2,480 lbs
 20% Max Load: 992 lbs

PICTURE OF SPECIMEN PRE-TEST



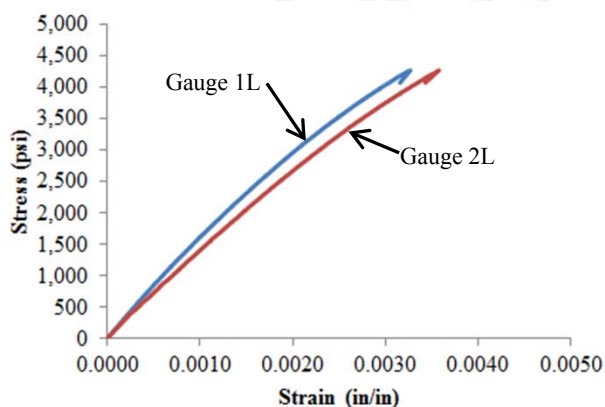
PICTURE OF SPECIMEN POST-TEST



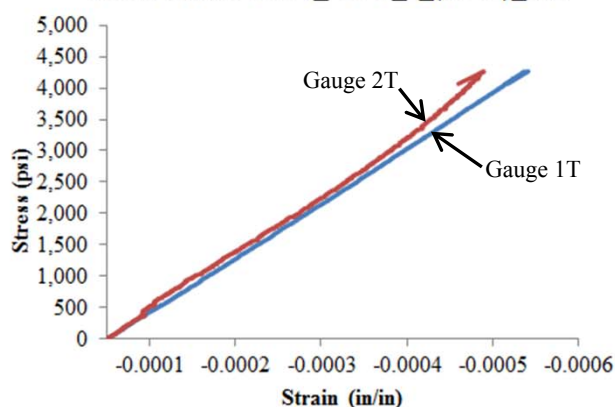
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001631 | 0.000593 | 1T | -0.000291 | -0.000117 | 0.1673 |
| 2L | 0.001850 | 0.000699 | 2T | -0.000276 | -0.000101 | 0.1524 |
| Average | | | | | | 0.1599 |

Stress-Strain Curve_-40°F_2_(08-02)_Long



Stress-Strain Curve_-40°F_2_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-N40-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-3-N40-FY08**
 Test Date: 8/10/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

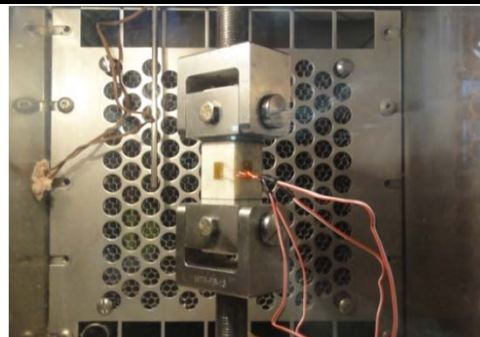
Maximum Load, P_z : 4,950 lbs
 Poisson's Ratio, v_{xz} : 0.0856

Measured Specimen Dimensions:

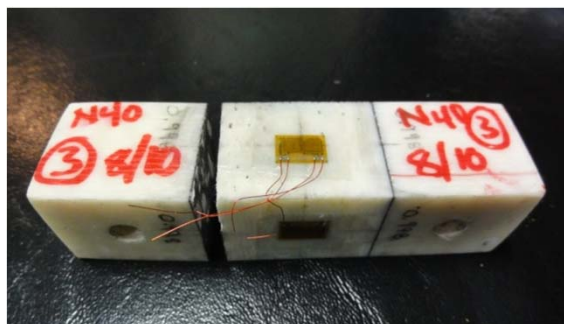
Thickness: 1.500 in
 Side 1: 0.998 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 2,475 lbs
 20% Max Load: 990 lbs

PICTURE OF SPECIMEN PRE-TEST



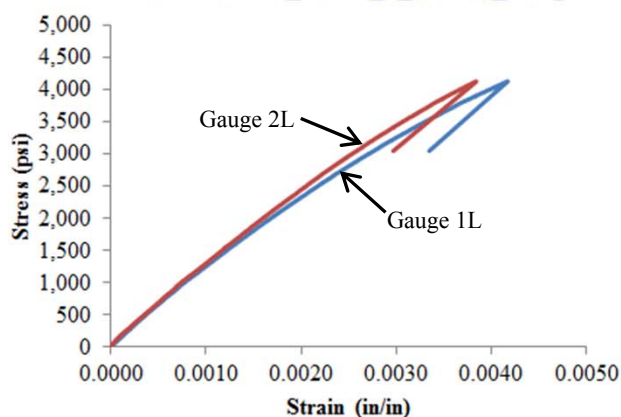
PICTURE OF SPECIMEN POST-TEST



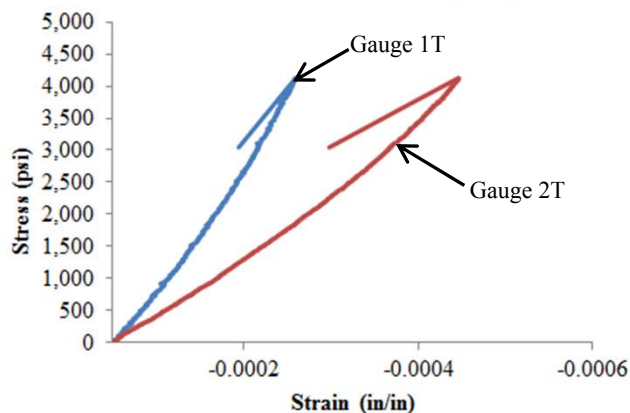
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002163 | 0.000770 | 1T | -0.000141 | -0.000063 | 0.0559 |
| 2L | 0.002042 | 0.000735 | 2T | -0.000270 | -0.000119 | 0.1154 |
| Average | | | | | | 0.0856 |

Stress-Strain Curve_-40°F_3_(08-02)_Long



Stress-Strain Curve_-40°F_3_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-N40-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-4-N40-FY08**
 Test Date: 8/10/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,960 lbs
 Poisson's Ratio, v_{xz} : 0.1156

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.999 in
 Side 2: 0.999 in

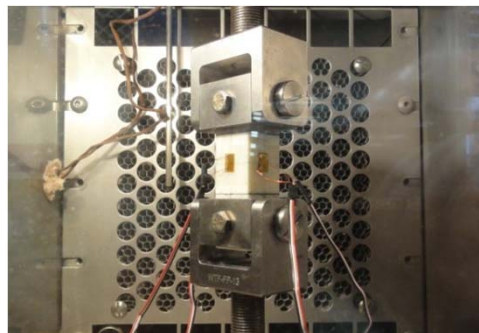
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,480 lbs

20% Max Load: 992 lbs

PICTURE OF SPECIMEN PRE-TEST



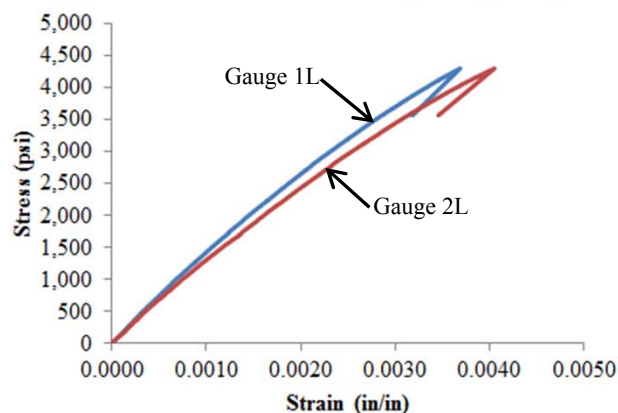
PICTURE OF SPECIMEN POST-TEST



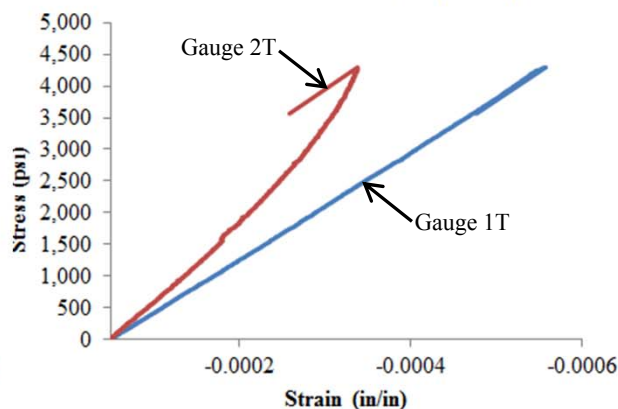
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001862 | 0.000675 | 1T | -0.000295 | -0.000120 | 0.1475 |
| 2L | 0.002054 | 0.000741 | 2T | -0.000196 | -0.000086 | 0.0837 |
| Average | | | | | | 0.1156 |

Stress-Strain Curve_-40°F_4_(08-02)_Long



Stress-Strain Curve_-40°F_4_(08-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-N40-FY08 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-5-N40-FY08**
 Test Date: 8/10/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

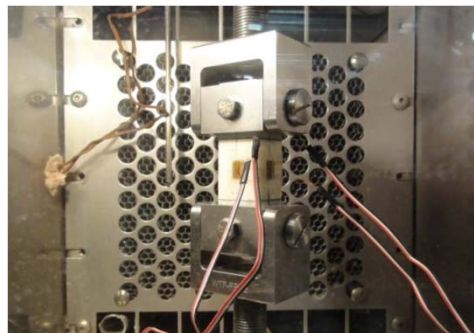
Maximum Load, P_z : 4,950 lbs
 Poisson's Ratio, v_{xz} : 0.0880

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.998 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,475 lbs
 20% Max Load: 990 lbs

PICTURE OF SPECIMEN PRE-TEST

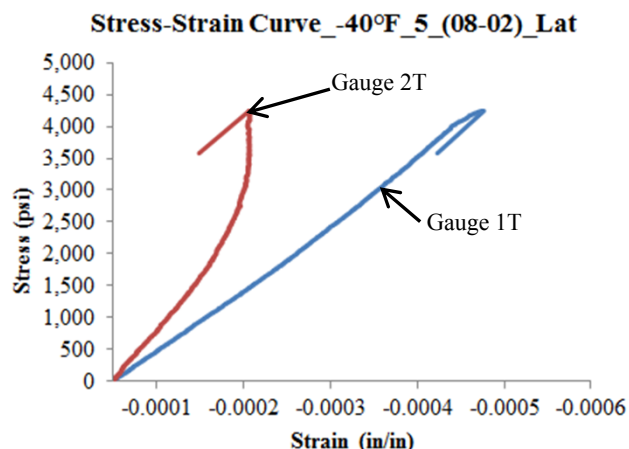
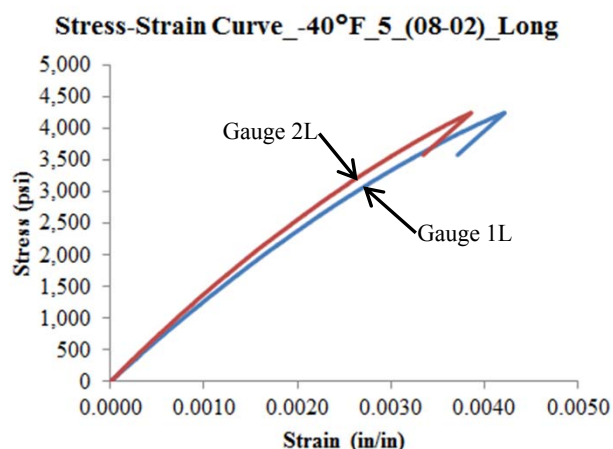


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002103 | 0.000777 | 1T | -0.000257 | -0.000105 | 0.1148 |
| 2L | 0.001936 | 0.000707 | 2T | -0.000137 | -0.000062 | 0.0612 |
| Average | | | | | | 0.0880 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-N40-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-OP-70-FY08
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: ν_{xz}
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1323
 Maximum Load, P_z : 3,616 lbs

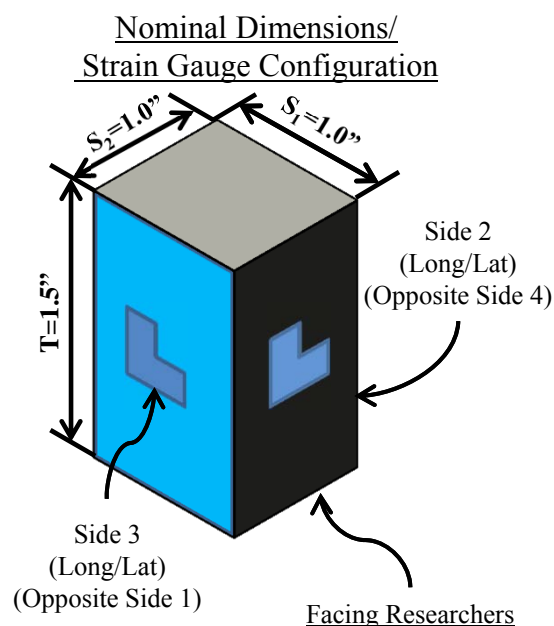
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|-------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT2-OP-1-70-FY08 | 3,612 | 0.1408 | Rupture |
| 2 | MAT2-OP-2-70-FY08 | 3,619 | 0.1468 | Rupture |
| 3 | MAT2-OP-3-70-FY08 | 3,616 | 0.1011 | Rupture |
| 4 | MAT2-OP-4-70-FY08 | 3,616 | 0.1274 | Rupture |
| 5 | MAT2-OP-5-70-FY08 | 3,619 | 0.1456 | Rupture |
| Average | | 3,616 | 0.1323 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Test Condition**Notes:**

- 1) Reference C-116 thru C-120 for individual specimen data.
- 2) Group of 5 specimens tested with representative data to report.
- 3) Max Load is based on MAT2-TX-70-FY08 strength data.
- 4) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.



TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-1-70-FY08**
 Test Date: 7/20/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,612 lbs
 Poisson's Ratio, v_{xz} : 0.1408

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.999 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,806 lbs

20% Max Load: 722 lbs

PICTURE OF SPECIMEN PRE-TEST



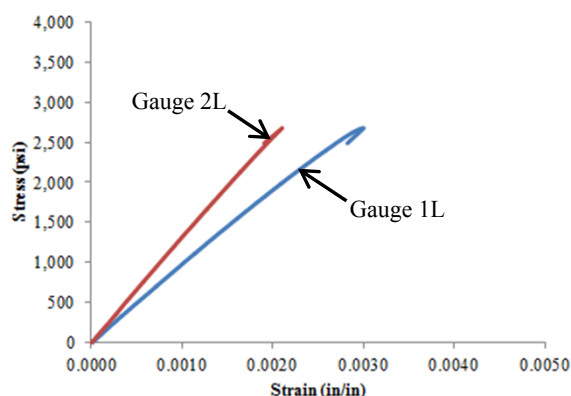
PICTURE OF SPECIMEN POST-TEST



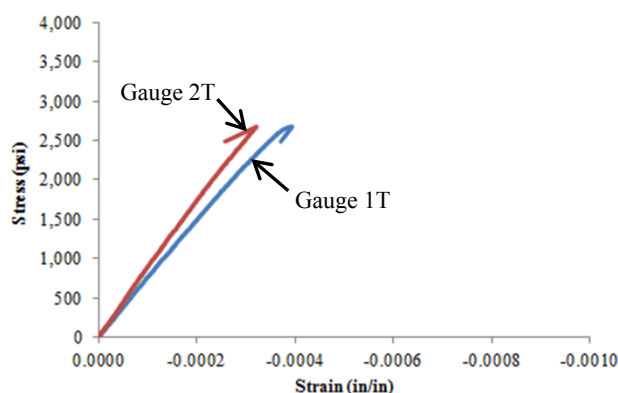
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001896 | 0.000734 | 1T | -0.000245 | -0.000095 | 0.1291 |
| 2L | 0.001389 | 0.000544 | 2T | -0.000209 | -0.000080 | 0.1525 |
| Average | | | | | | 0.1408 |

Stress-Strain Curve_70_1_(08-02)_Long



Stress-Strain Curve_70_1_(08-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-70-FY08 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-2-70-FY08**
 Test Date: 7/20/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,619 lbs
 Poisson's Ratio, v_{xz} : 0.1468

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 1.001 in
 Side 2: 0.998 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,810 lbs
 20% Max Load: 724 lbs

PICTURE OF SPECIMEN PRE-TEST



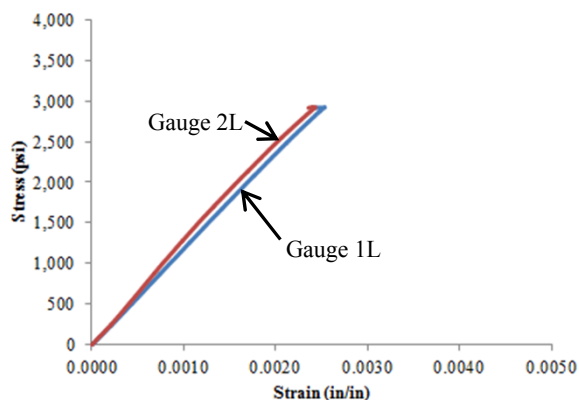
PICTURE OF SPECIMEN POST-TEST



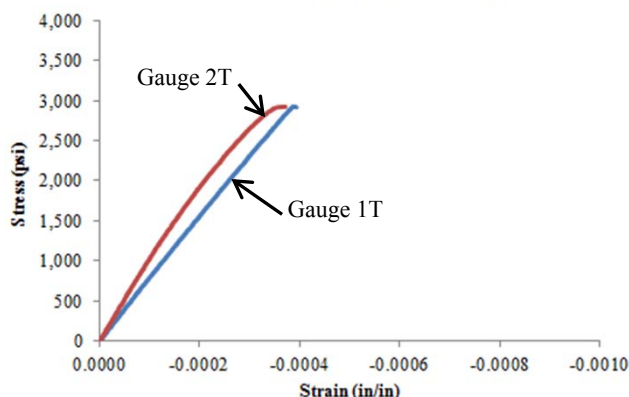
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001534 | 0.000618 | 1T | -0.000234 | -0.000091 | 0.1554 |
| 2L | 0.001420 | 0.000566 | 2T | -0.000187 | -0.000069 | 0.1382 |
| Average | | | | | | 0.1468 |

Stress-Strain Curve_70_2_(08-02)_Long



Stress-Strain Curve_70_2_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-70-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-3-70-FY08**
 Test Date: 7/20/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,616 lbs
 Poisson's Ratio, v_{xz} : 0.1011

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.999 in
 Side 2: 0.999 in

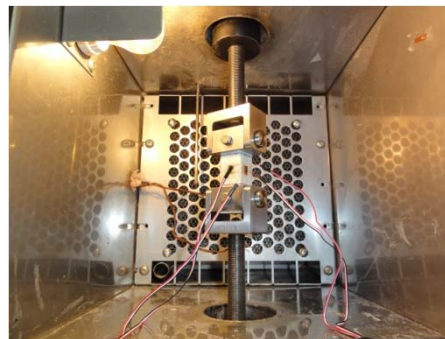
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,808 lbs

20% Max Load: 723 lbs

PICTURE OF SPECIMEN PRE-TEST



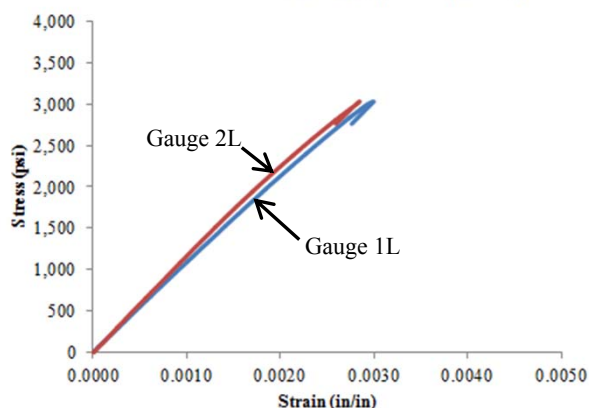
PICTURE OF SPECIMEN POST-TEST



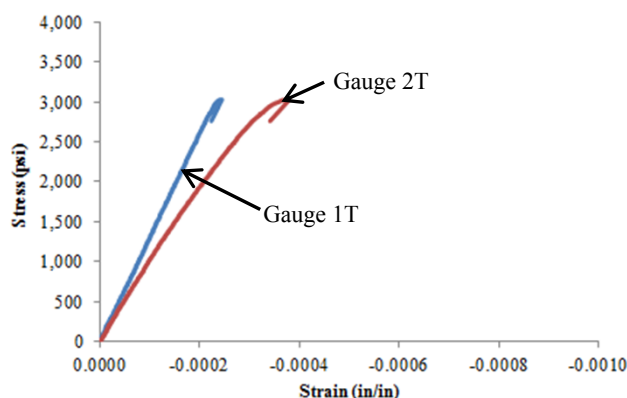
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001686 | 0.000657 | 1T | -0.000139 | -0.000056 | 0.0810 |
| 2L | 0.001578 | 0.000619 | 2T | -0.000186 | -0.000070 | 0.1212 |
| Average | | | | | | 0.1011 |

Stress-Strain Curve_70_3_(08-02)_Long



Stress-Strain Curve_70_3_(08-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-70-FY08 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-4-70-FY08**
 Test Date: 7/20/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,616 lbs
 Poisson's Ratio, v_{xz} : 0.1274

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 1.000 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

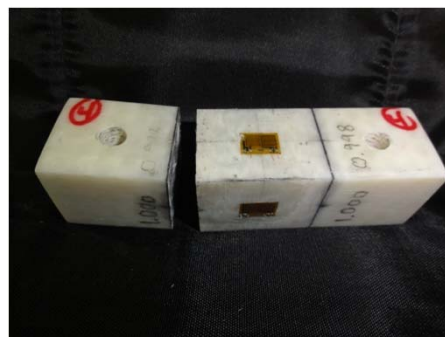
50% Max Load: 1,808 lbs

20% Max Load: 723 lbs

PICTURE OF SPECIMEN PRE-TEST



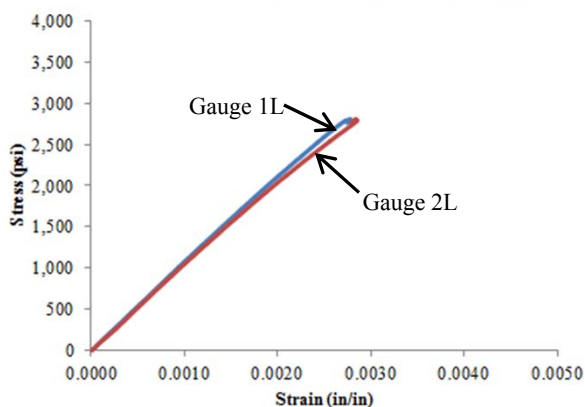
PICTURE OF SPECIMEN POST-TEST



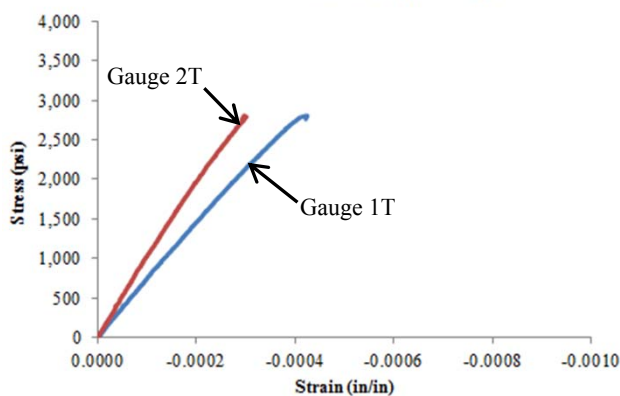
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001703 | 0.000671 | 1T | -0.000251 | -0.000097 | 0.1495 |
| 2L | 0.001761 | 0.000688 | 2T | -0.000182 | -0.000069 | 0.1053 |
| Average | | | | | | 0.1274 |

Stress-Strain Curve_70_4_(08-02)_Long



Stress-Strain Curve_70_4_(08-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-70-FY08 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-5-70-FY08**
 Test Date: 7/20/2012
 Specimen Received: 4/23/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,619 lbs
 Poisson's Ratio, v_{xz} : 0.1456

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 1.000 in
 Side 2: 0.999 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,810 lbs
 20% Max Load: 724 lbs

PICTURE OF SPECIMEN PRE-TEST



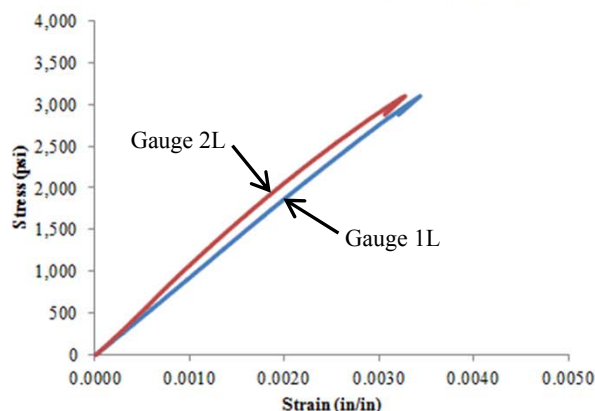
PICTURE OF SPECIMEN POST-TEST



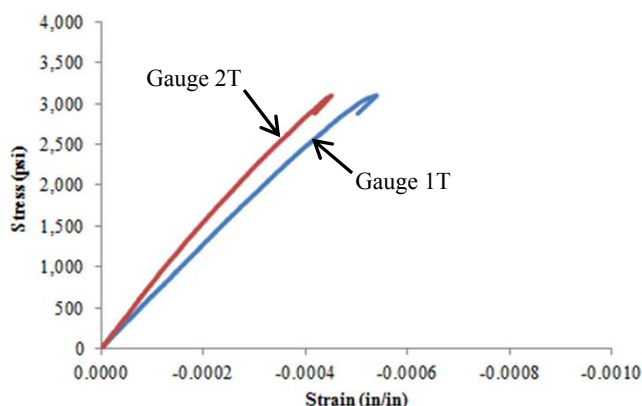
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001937 | 0.000783 | 1T | -0.000286 | -0.000112 | 0.1508 |
| 2L | 0.001736 | 0.000674 | 2T | -0.000238 | -0.000089 | 0.1404 |
| Average | | | | | | 0.1456 |

Stress-Strain Curve_70_5_(08-02)_Long



Stress-Strain Curve_70_5_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-70-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

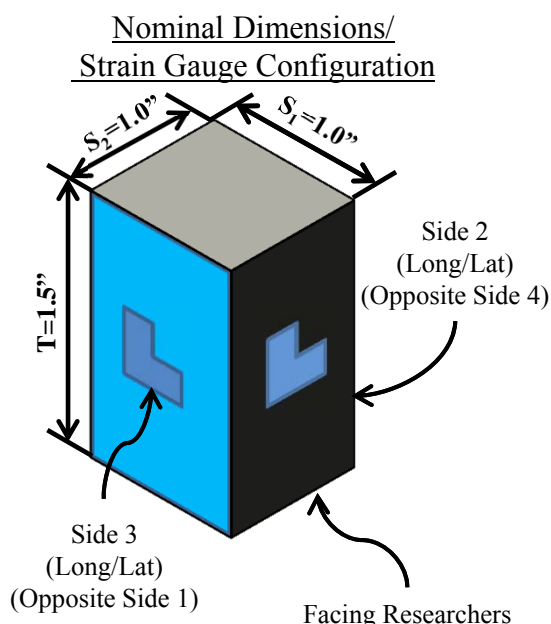
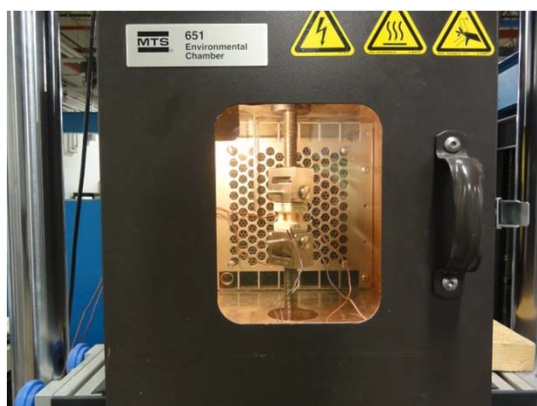
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-OP-140-FY08**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **ν_{xz}**
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **-0.0371**
 Maximum Load, P_z : **1,868 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT2-OP-1-140-FY08 | 1,867 | -0.0598 | Bondline |
| 2 | MAT2-OP-2-140-FY08 | 1,865 | -0.0315 | Bondline |
| 3 | MAT2-OP-3-140-FY08 | 1,867 | 0.0093 | Bondline |
| 4 | MAT2-OP-4-140-FY08 | 1,867 | -0.0455 | Bondline |
| 5 | MAT2-OP-5-140-FY08 | 1,873 | -0.0579 | Bondline |
| Average | | 1,868 | -0.0371 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1.5”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) Reference C-122 thru C-126 for individual specimen data.
- 2) 14 specimens tested . Group of 5 shown with relevant data to report.
- 3) Max Load is based on MAT2-TZ-140-FY09 strength data.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-1-140-FY08**
 Test Date: 9/5/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

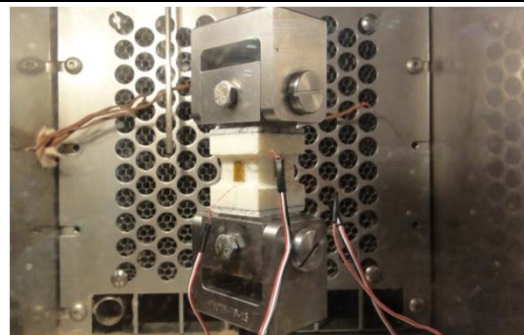
Maximum Load, P_z : 1,867 lbs
 Poisson's Ratio, v_{xz} : -0.0598

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.988 in
 Side 2: 0.992 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 934 lbs
 20% Max Load: 373 lbs

PICTURE OF SPECIMEN PRE-TEST



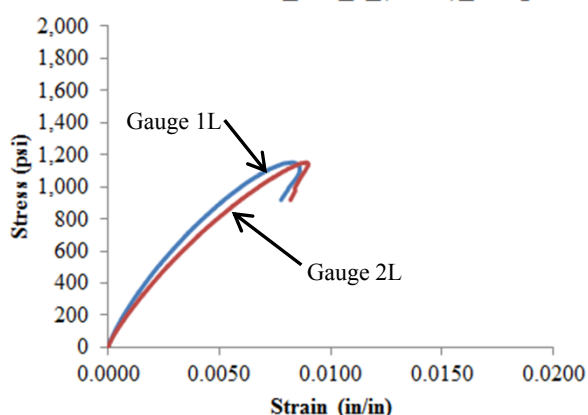
PICTURE OF SPECIMEN POST-TEST



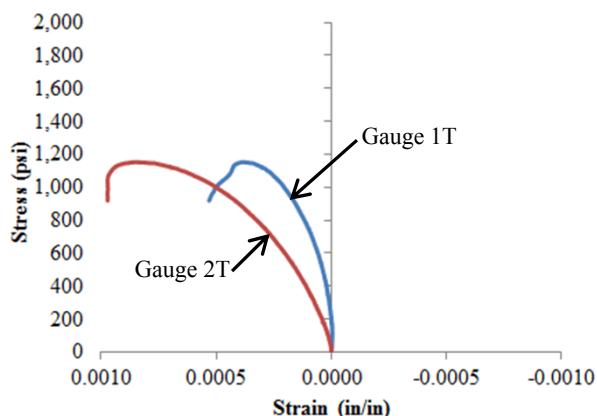
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|-------------------------------|--------------------------------|----------------|-------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.005502 | 0.001568 | 1T | 0.000179 | 0.000019 | -0.0409 |
| 2L | 0.006271 | 0.001885 | 2T | 0.000449 | 0.000103 | -0.0788 |
| Average | | | | | | -0.0598 |

Stress-Strain Curve_140_9_(08-02)_Long



Stress-Strain Curve_140_9_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-140-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-2-140-FY08**
 Test Date: 9/5/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

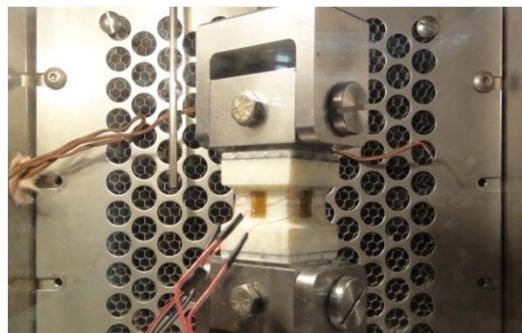
Average Material Properties:

Maximum Load, P_z : 1,865 lbs
 Poisson's Ratio, v_{xz} : -0.0315

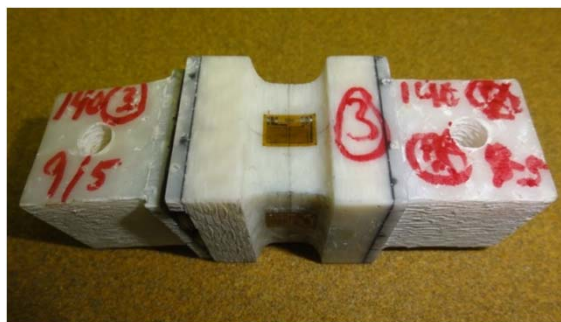
Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.993 in
 Side 2: 0.986 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 933 lbs
 20% Max Load: 373 lbs

PICTURE OF SPECIMEN PRE-TEST



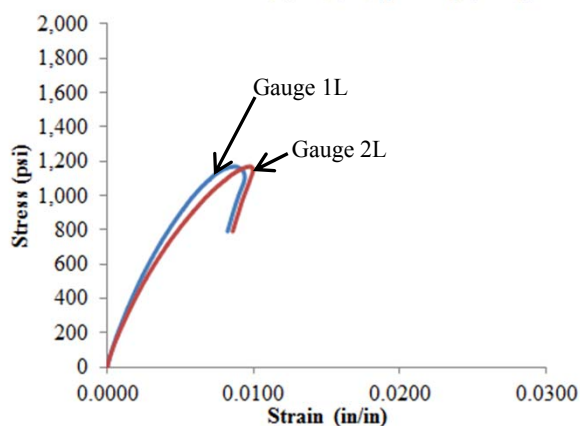
PICTURE OF SPECIMEN POST-TEST



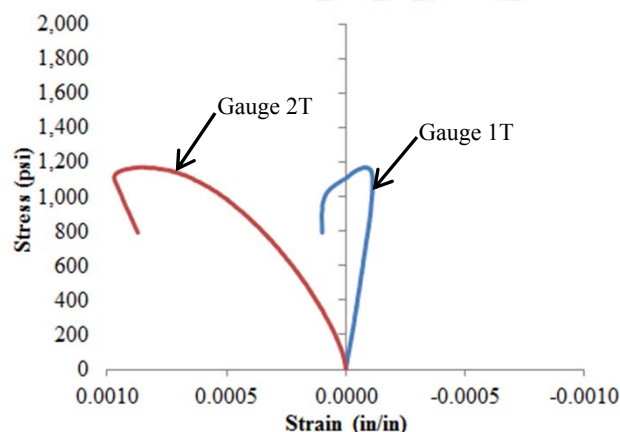
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|-------------------------------|--------------------------------|----------------|-------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.005460 | 0.001582 | 1T | -0.000106 | -0.000047 | 0.0152 |
| 2L | 0.006337 | 0.001801 | 2T | 0.000470 | 0.000115 | -0.0782 |
| Average | | | | | | -0.0315 |

Stress-Strain Curve_140_11_(08-02)_Long



Stress-Strain Curve_140_11_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-140-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-3-140-FY08**
 Test Date: 9/5/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

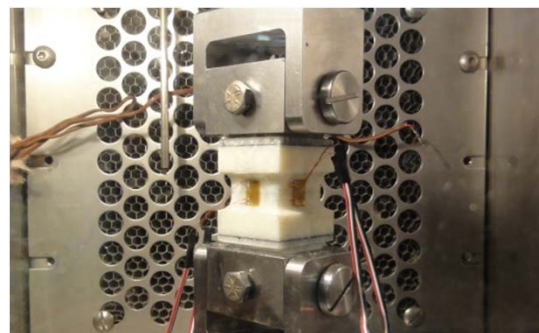
Maximum Load, P_z : 1,867 lbs
 Poisson's Ratio, v_{xz} : 0.0093

Measured Specimen Dimensions:

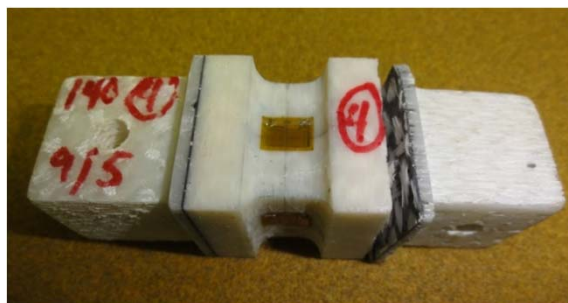
Thickness: 1.500 in
 Side 1: 0.993 in
 Side 2: 0.987 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 934 lbs
 20% Max Load: 373 lbs

PICTURE OF SPECIMEN PRE-TEST

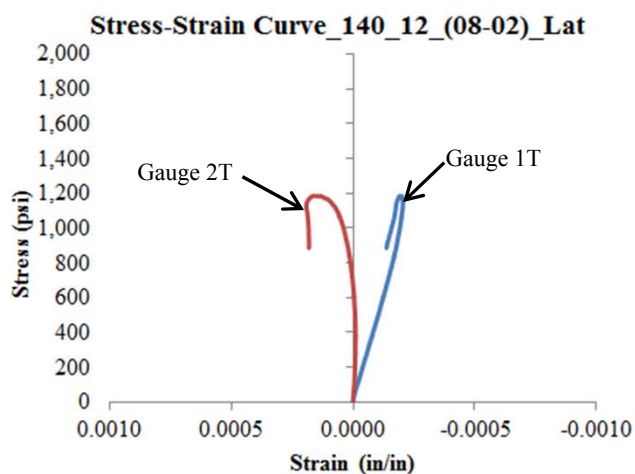
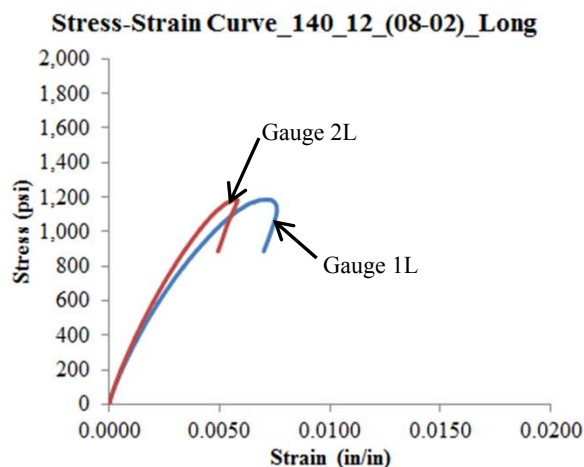


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|-------------------------------|--------------------------------|----------------|-------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.004395 | 0.001280 | 1T | -0.000185 | -0.000078 | 0.0343 |
| 2L | 0.003757 | 0.001156 | 2T | 0.000031 | -0.000010 | -0.0158 |
| Average | | | | | | 0.0093 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-140-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-4-70-FY08**
 Test Date: 9/6/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

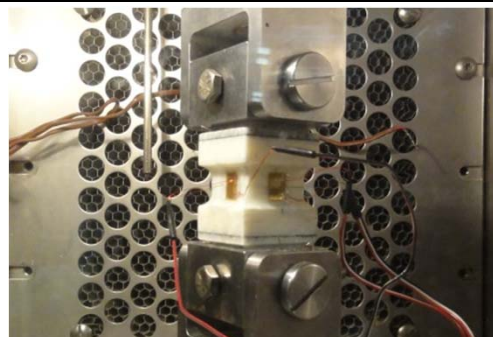
Maximum Load, P_z : 1,867 lbs
 Poisson's Ratio, v_{xz} : -0.0455

Measured Specimen Dimensions:

Thickness: 1.500 in
 Side 1: 0.992 in
 Side 2: 0.988 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 934 lbs
 20% Max Load: 373 lbs

PICTURE OF SPECIMEN PRE-TEST

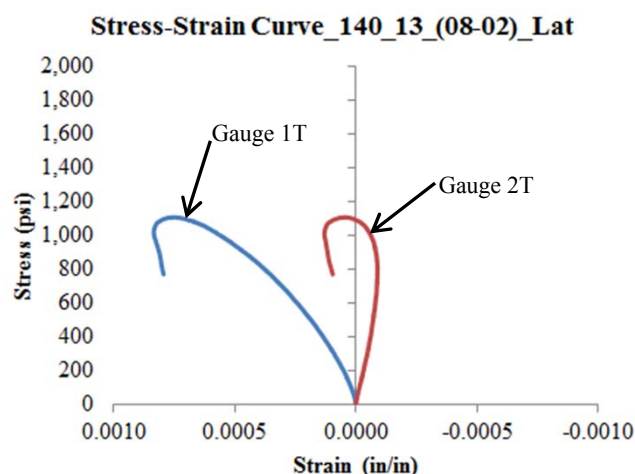
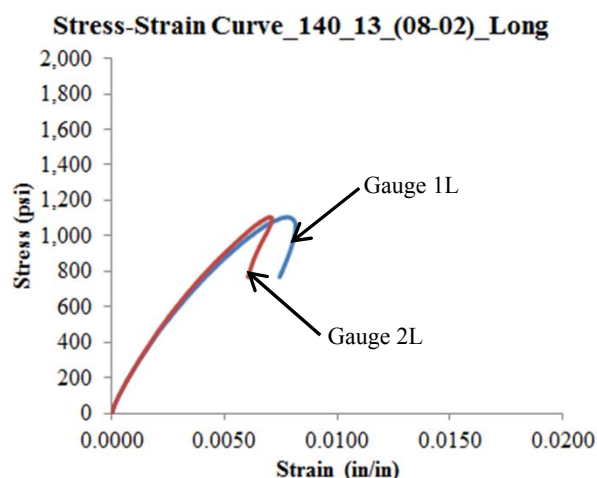


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|-------------------------------|--------------------------------|----------------|-------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.005698 | 0.001660 | 1T | 0.000510 | 0.000126 | -0.0951 |
| 2L | 0.005416 | 0.001632 | 2T | -0.000074 | -0.000059 | 0.0042 |
| Average | | | | | | -0.0455 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-140-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-5-140-FY08**
 Test Date: 9/6/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

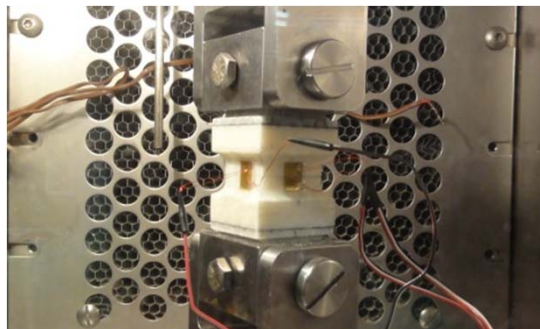
Maximum Load, P_z : 1,873 lbs
 Poisson's Ratio, v_{xz} : -0.0579

Measured Specimen Dimensions:

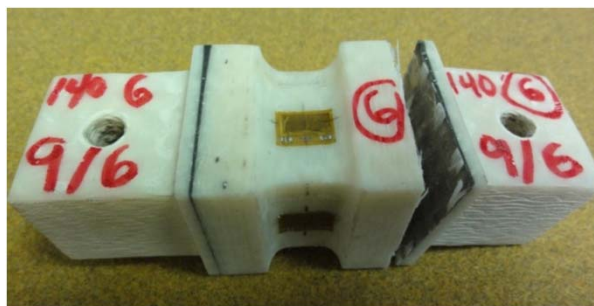
Thickness: 1.500 in
 Side 1: 0.993 in
 Side 2: 0.990 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 936 lbs
 20% Max Load: 375 lbs

PICTURE OF SPECIMEN PRE-TEST



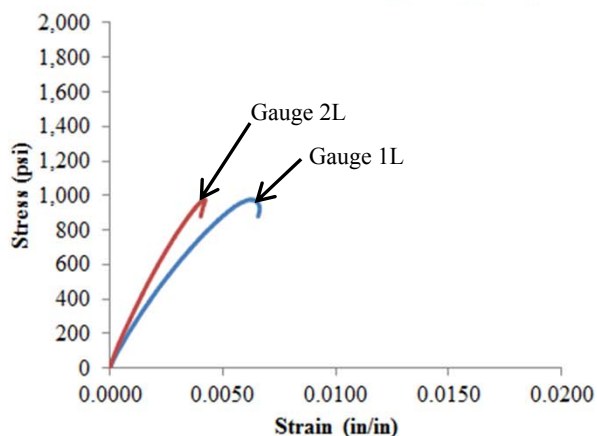
PICTURE OF SPECIMEN POST-TEST



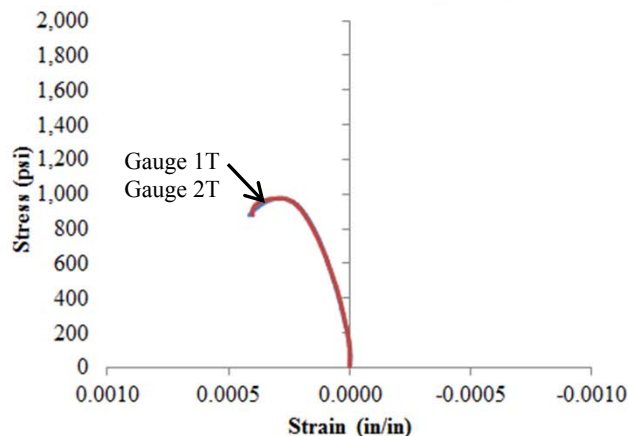
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|-------------------------------|--------------------------------|----------------|-------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.005514 | 0.001711 | 1T | 0.000214 | 0.000040 | -0.0459 |
| 2L | 0.003817 | 0.001252 | 2T | 0.000217 | 0.000038 | -0.0698 |
| Average | | | | | | -0.0579 |

Stress-Strain Curve_140_14_(08-02)_Long



Stress-Strain Curve_140_14_(08-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT2-TZ-140-FY08 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX D

MATERIAL 1-FY09 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TX-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 24,484 | lbs |
| Tensile Strength, ST_x : | 51,176 | psi |
| Tensile Modulus, E_x : | 2,225,572 | psi |
| Ultimate Strain, ϵ_x : | 0.0330 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2671 | |

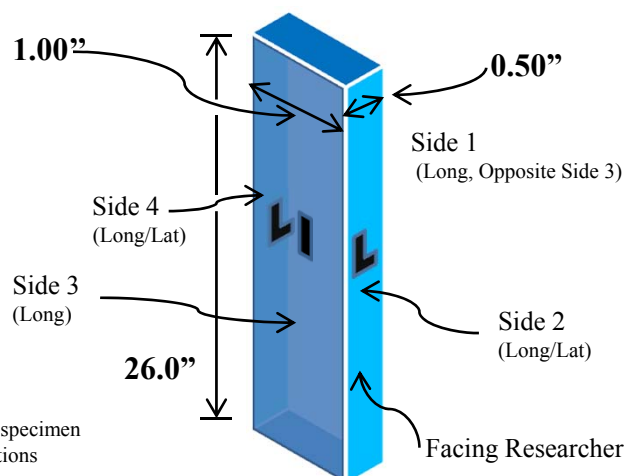
| Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-------------------------------|-----------------------------------|---------------------------------|--|-----------------------------|--------------|
| MAT1-TX-1-N40-FY09 | 24,327 | 51,972 | 2,277,282 | 0.0228 | 0.2579 | SMV |
| MAT1-TX-2-N40-FY09 | 25,085 | 52,415 | 2,232,325 | 0.0235 | 0.2233 | SMV |
| MAT1-TX-3-N40-FY09 | 23,728 | 49,030 | 2,166,656 | 0.0226 | 0.2699 | SMV |
| MAT1-TX-4-N40-FY09 | 25,355 | 52,278 | 2,268,607 | 0.0230 | 0.3283 | SMV |
| MAT1-TX-5-N40-FY09 | 23,924 | 50,184 | 2,182,988 | 0.0230 | 0.2560 | SMV |
| Average | 24,484 | 51,176 | 2,225,572 | 0.0230 | 0.2671 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) 11 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) SMV corresponds with S=long splitting, M=multiple areas, V=various positions
- 4) See D-2 to D-6 for individual specimen results
- 5) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-N40-FY09**
 Test Date: 1/23/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_x , E_x , ν_{xy}

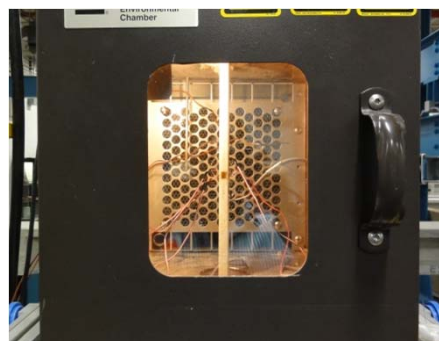
Average Material Properties:

Ultimate Load, P_x : 24,327 lbs
 Tensile Strength, ST_x : 51,972 psi
 Tensile Modulus, E_x : 2,277,282 psi
 Ultimate Strain, ϵ_x : 0.0228 in/in
 Poisson's Ratio, ν_{xy} : 0.2579

Measured Specimen Dimensions:

Width, W: 0.4978 in
 Thickness, H: 0.9403 in
 Laboratory Temperature: 68°F
 Failure Mode: SMV
 20% Max Load: 4,865 lbs
 50% Max Load: 12,164 lbs

PICTURE OF SPECIMEN PRE-TEST



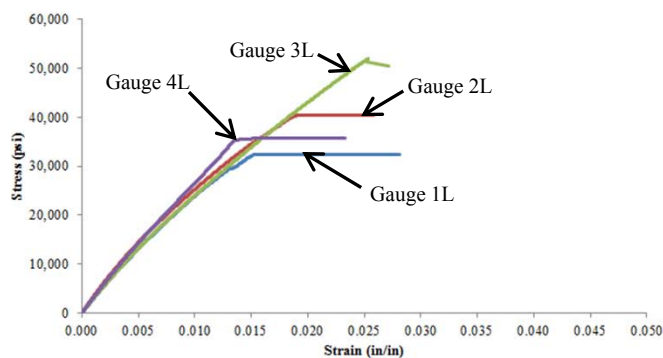
PICTURE OF SPECIMEN POST-TEST



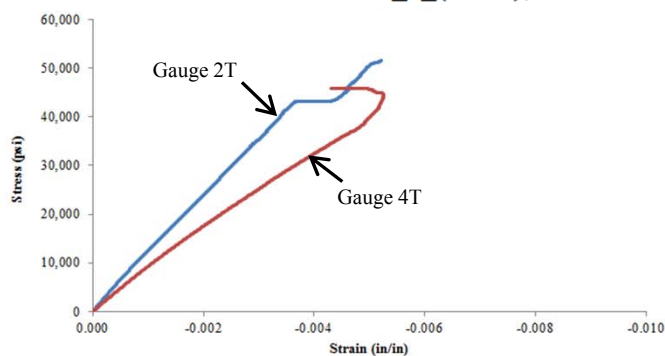
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_x (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0111 | 0.0039 | 2,161,480 | | | | |
| 2L | 0.0104 | 0.0034 | 2,251,046 | 2T | -0.0022 | -0.0008 | 0.1970 |
| 3L | 0.0110 | 0.0038 | 2,191,278 | | | | |
| 4L | 0.0098 | 0.0035 | 2,505,323 | 4T | -0.0031 | -0.0011 | 0.3187 |
| Average | | | 2,277,282 | | | | 0.2579 |

Stress-Strain Curve -40_1_(09-01), Long.



Stress-Strain Curve -40_1_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-2-N40-FY09**
 Test Date: 7/3/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_x , E_x , ν_{xy}

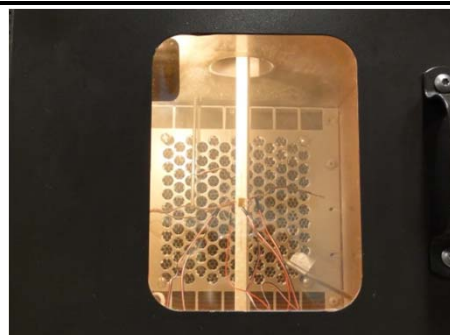
Average Material Properties:

Ultimate Load, P_x : 25,085 lbs
 Tensile Strength, ST_x : 52,415 psi
 Tensile Modulus, E_x : 2,232,325 psi
 Ultimate Strain, ϵ_x : 0.0235 in/in
 Poisson's Ratio, ν_{xy} : 0.2233

Measured Specimen Dimensions:

Width, W: 0.5160 in
 Thickness, H: 0.9275 in
 Laboratory Temperature: 68°F
 Failure Mode: SMV
 20% Max Load: 5,017 lbs
 50% Max Load: 12,543 lbs

PICTURE OF SPECIMEN PRE-TEST



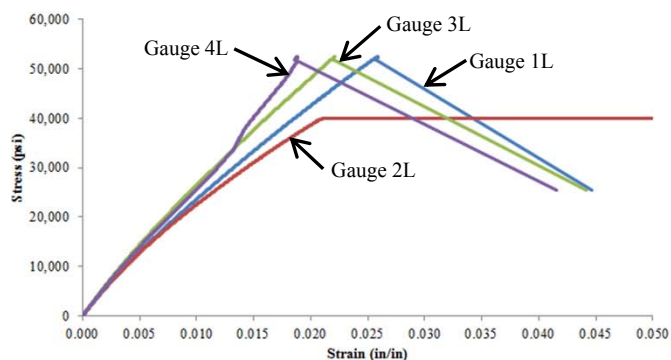
PICTURE OF SPECIMEN POST-TEST



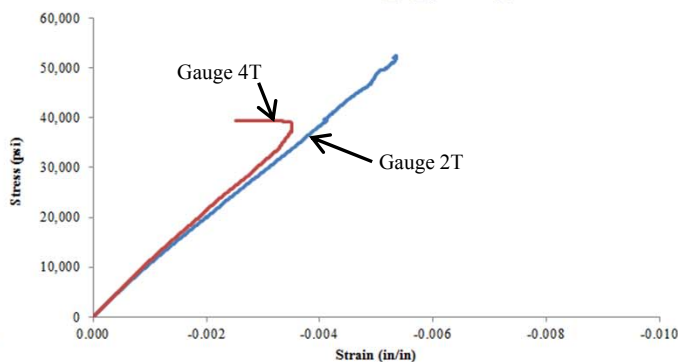
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_x (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0113 | 0.0039 | 2,140,535 | | | | |
| 2L | 0.0121 | 0.0040 | 1,936,971 | 2T | -0.0027 | -0.0010 | 0.2081 |
| 3L | 0.0099 | 0.0035 | 2,470,412 | | | | |
| 4L | 0.0102 | 0.0036 | 2,381,382 | 4T | -0.0025 | -0.0009 | 0.2385 |
| Average | | | 2,232,325 | | | | 0.2233 |

Stress-Strain Curve -40_2_(09-01), Long.



Stress-Strain Curve -40_2_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-3-N40-FY09**
 Test Date: 7/3/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_x , E_x , v_{xy}

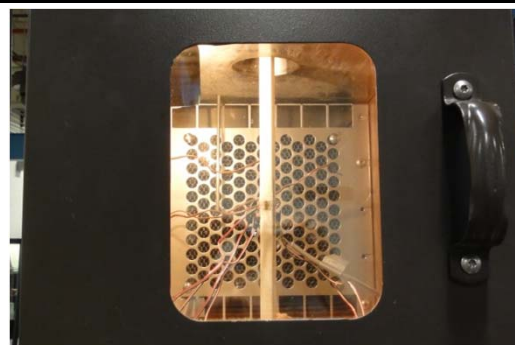
Average Material Properties:

Ultimate Load, P_x : 23,728 lbs
 Tensile Strength, ST_x : 49,030 psi
 Tensile Modulus, E_x : 2,166,656 psi
 Ultimate Strain, ϵ_x : 0.0226 in/in
 Poisson's Ratio, v_{xy} : 0.2699

Measured Specimen Dimensions:

Width, W: 0.4989 in
 Thickness, H: 0.9391 in
 Laboratory Temperature: 68°F
 Failure Mode: SMV
 20% Max Load: 4,746 lbs
 50% Max Load: 11,864 lbs

PICTURE OF SPECIMEN PRE-TEST



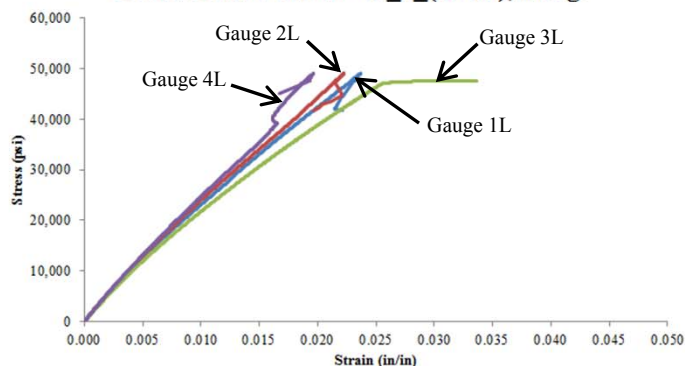
PICTURE OF SPECIMEN POST-TEST



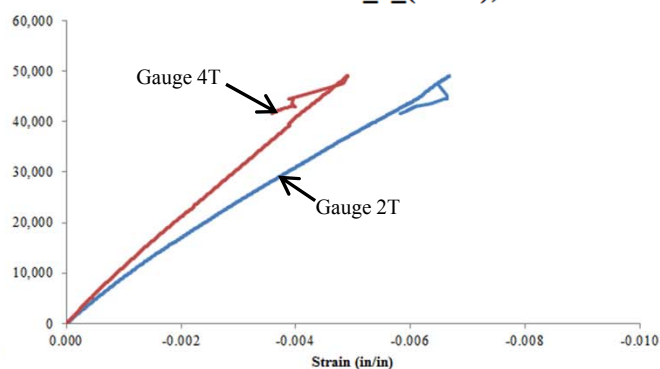
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_x (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0107 | 0.0038 | 2,113,102 | | | | |
| 2L | 0.0102 | 0.0037 | 2,241,807 | 2T | -0.0030 | -0.0011 | 0.3007 |
| 3L | 0.0115 | 0.0040 | 1,963,960 | | | | |
| 4L | 0.0099 | 0.0036 | 2,347,755 | 4T | -0.0024 | -0.0009 | 0.2391 |
| Average | | | 2,166,656 | | | | 0.2699 |

Stress-Strain Curve -40_3_(09-01), Long.



Stress-Strain Curve -40_3_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-4-N40-FY09**
 Test Date: 7/3/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_x , E_x , ν_{xy}

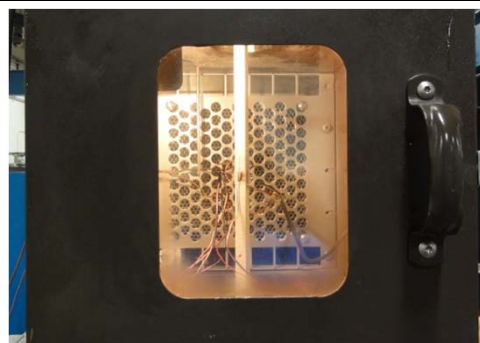
Average Material Properties:

Ultimate Load, P_x : 25,355 lbs
 Tensile Strength, ST_x : 52,278 psi
 Tensile Modulus, E_x : 2,268,607 psi
 Ultimate Strain, ϵ_x : 0.0230 in/in
 Poisson's Ratio, ν_{xy} : 0.1642

Measured Specimen Dimensions:

Width, W: 0.5215 in
 Thickness, H: 0.9300 in
 Laboratory Temperature: 68°F
 Failure Mode: SMV
 20% Max Load: 5,071 lbs
 50% Max Load: 12,677 lbs

PICTURE OF SPECIMEN PRE-TEST



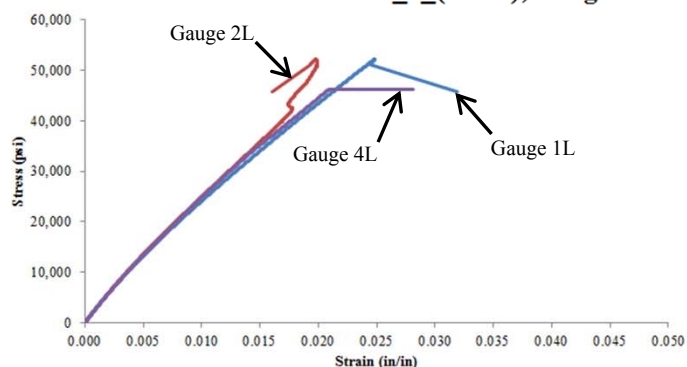
PICTURE OF SPECIMEN POST-TEST



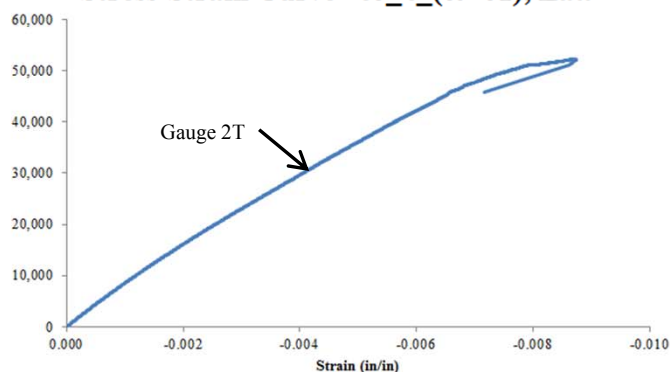
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_x (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0110 | 0.0038 | 2,185,758 | | | | |
| 2L | 0.0105 | 0.0037 | 2,310,341 | 2T | -0.0035 | -0.0012 | 0.3283 |
| 3L | Lost Gauge | | | | | | |
| 4L | 0.0106 | 0.0038 | 2,309,723 | 4T | Lost Gauge | | |
| Average | | | 2,268,607 | | | | 0.3283 |

Stress-Strain Curve -40_4_(09-01), Long.



Stress-Strain Curve -40_4_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-N40-FY09**
 Test Date: 7/10/2012
 Specimen Received: 4/23/2012
 Properties Measured: ST_x , E_x , v_{xy}

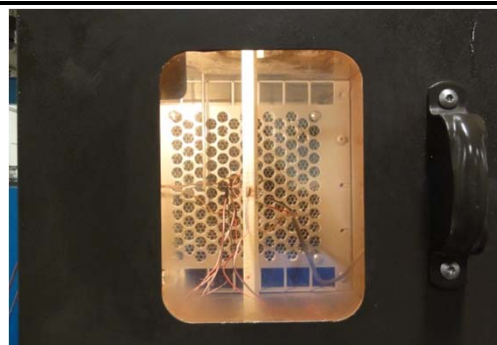
Average Material Properties:

Ultimate Load, P_x : 23,924 lbs
 Tensile Strength, ST_x : 50,184 psi
 Tensile Modulus, E_x : 2,182,988 psi
 Ultimate Strain, ϵ_x : 0.0230 in/in
 Poisson's Ratio, v_{xy} : 0.2560

Measured Specimen Dimensions:

Width, W: 0.5115 in
 Thickness, H: 0.9320 in
 Laboratory Temperature: 68°F
 Failure Mode: SMV
 20% Max Load: 4,785 lbs
 50% Max Load: 11,962 lbs

PICTURE OF SPECIMEN PRE-TEST



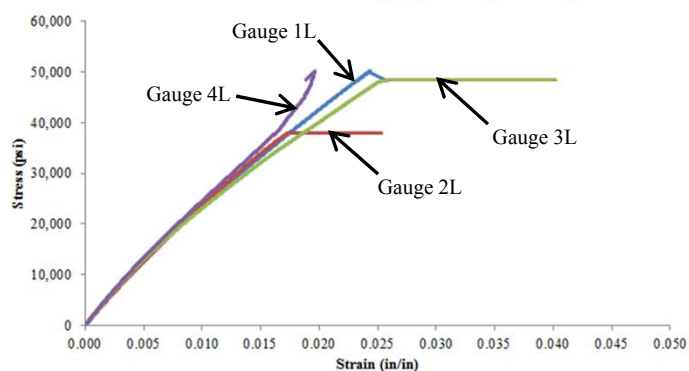
PICTURE OF SPECIMEN POST-TEST



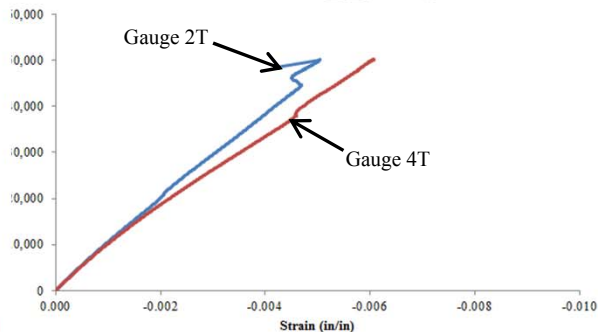
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_x (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0107 | 0.0037 | 2,153,842 | | | | |
| 2L | 0.0106 | 0.0039 | 2,247,284 | 2T | -0.0025 | -0.0009 | 0.2305 |
| 3L | 0.0111 | 0.0037 | 2,054,532 | | | | |
| 4L | 0.0102 | 0.0036 | 2,276,293 | 4T | -0.0028 | -0.0010 | 0.2815 |
| Average | | | 2,182,988 | | | | 0.2560 |

Stress-Strain Curve -40_5_(09-01), Long.



Stress-Strain Curve -40_5_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

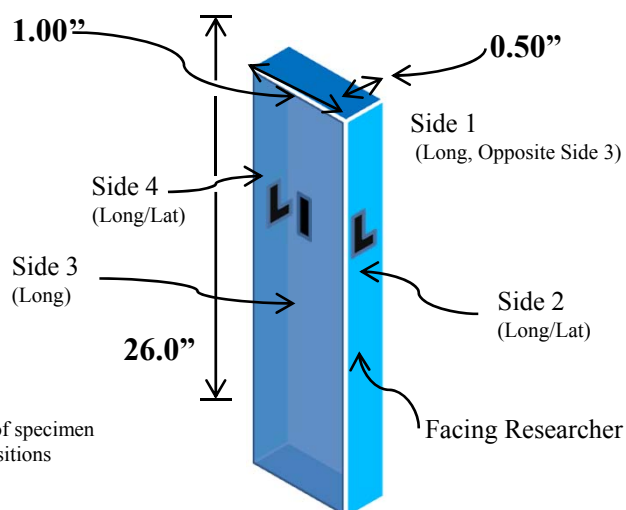
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-TX-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **ST_x , E_x , ν_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : **22,235** **lbs**
 Tensile Strength, ST_x : **45,188** **psi**
 Tensile Modulus, E_x : **2,036,733** **psi**
 Ultimate Strain, ϵ_x : **0.0222** **in/in**
 Poisson's Ratio, ν_{xy} : **0.2491**

| Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|-------------------|-------------------------------|-----------------------------------|---------------------------------|--|-----------------------------|--------------|
| MAT1-TX-1-70-FY09 | 21,831 | 46,425 | 2,008,787 | 0.0231 | 0.2946 | DGM, SMV |
| MAT1-TX-2-70-FY09 | 21,676 | 46,434 | 2,054,197 | 0.0226 | 0.3529 | DGM, SMV |
| MAT1-TX-3-70-FY09 | 21,001 | 44,824 | 1,986,708 | 0.0226 | 0.2237 | DGM, SMV |
| MAT1-TX-4-70-FY09 | 23,130 | 44,084 | 2,051,203 | 0.0215 | 0.1621 | DGM, SMV |
| MAT1-TX-5-70-FY09 | 23,534 | 44,173 | 2,082,773 | 0.0212 | 0.2124 | DGM, SMV |
| Average | 22,235 | 45,188 | 2,036,733 | 0.0222 | 0.2491 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) SMV corresponds with S=long splitting, M=multiple areas, V=various positions
- 4) See D-8 to D-12 for individual specimen results
- 5) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-70-FY09**
 Test Date: 1/10/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 21,831 lbs
 Tensile Strength, ST_x : 46,425 psi
 Tensile Modulus, E_x : 2,008,787 psi
 Ultimate Strain, ϵ_x : 0.0231 in/in
 Poisson's Ratio, ν_{xy} : 0.2946

Measured Specimen Dimensions:

Width, W: 0.4992 in
 Thickness, H: 0.9420 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM, SMV
 20% Max Load: 4,366 lbs
 50% Max Load: 10,916 lbs

PICTURE OF SPECIMEN PRE-TEST



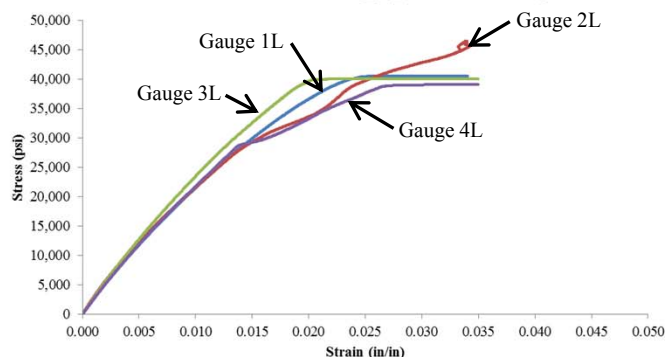
PICTURE OF SPECIMEN POST-TEST



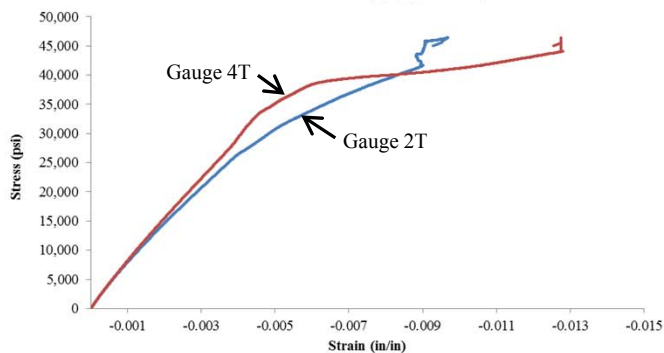
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0109 | 0.0038 | 1,955,417 | | | | |
| 2L | 0.0110 | 0.0036 | 1,881,057 | 2T | -0.0034 | -0.0012 | 0.3025 |
| 3L | 0.0099 | 0.0035 | 2,196,273 | | | | |
| 4L | 0.0108 | 0.0038 | 2,002,400 | 4T | -0.0031 | -0.0011 | 0.2867 |
| Average | | | 2,008,787 | | | | 0.2946 |

Stress-Strain Curve 70_1_(09-01), Long.



Stress-Strain Curve 70_1_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-2-70-FY09**
 Test Date: 1/10/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

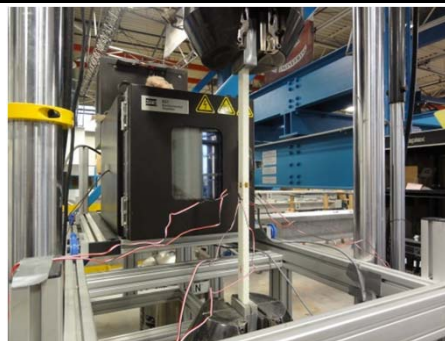
Average Material Properties:

Ultimate Load, P_x : 21,676 lbs
 Tensile Strength, ST_x : 46,434 psi
 Tensile Modulus, E_x : 2,054,197 psi
 Ultimate Strain, ϵ_x : 0.0226 in/in
 Poisson's Ratio, ν_{xy} : 0.3529

Measured Specimen Dimensions:

Width, W: 0.4981 in
 Thickness, H: 0.9372 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM, SMV
 20% Max Load: 4,335 lbs
 50% Max Load: 10,838 lbs

PICTURE OF SPECIMEN PRE-TEST



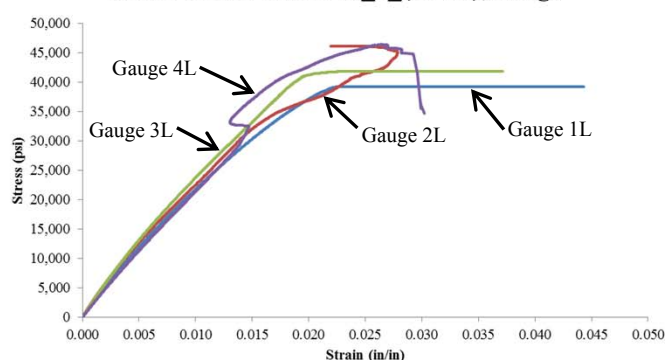
PICTURE OF SPECIMEN POST-TEST



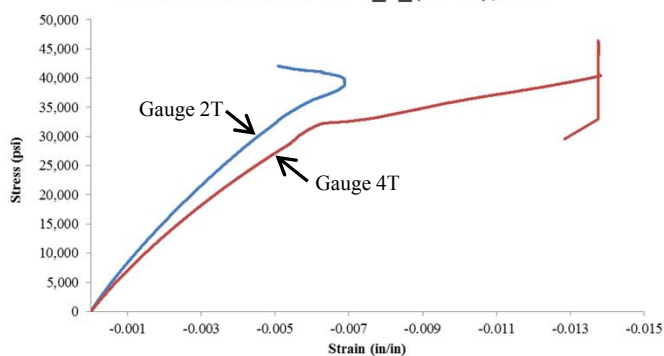
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0108 | 0.0038 | 1,982,591 | | | | |
| 2L | 0.0104 | 0.0035 | 2,019,131 | 2T | -0.0033 | -0.0011 | 0.3121 |
| 3L | 0.0097 | 0.0034 | 2,191,672 | | | | |
| 4L | 0.0109 | 0.0040 | 2,023,394 | 4T | -0.0041 | -0.0014 | 0.3938 |
| Average | | | 2,054,197 | | | | 0.3529 |

Stress-Strain Curve 70_2_(09-01), Long.



Stress-Strain Curve 70_2_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MAT1-TX-3-70-FY09
 Test Date: 1/11/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

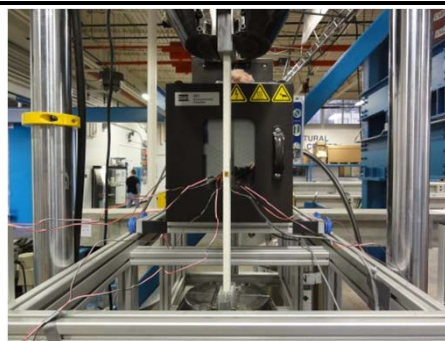
Average Material Properties:

Ultimate Load, P_x : 21,001 lbs
 Tensile Strength, ST_x : 44,824 psi
 Tensile Modulus, E_x : 1,986,708 psi
 Ultimate Strain, ϵ_x : 0.0226 in/in
 Poisson's Ratio, ν_{xy} : 0.2237

Measured Specimen Dimensions:

Width, W: 0.4989 in
 Thickness, H: 0.9391 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM, SMV
 20% Max Load: 4,200 lbs
 50% Max Load: 10,500 lbs

PICTURE OF SPECIMEN PRE-TEST



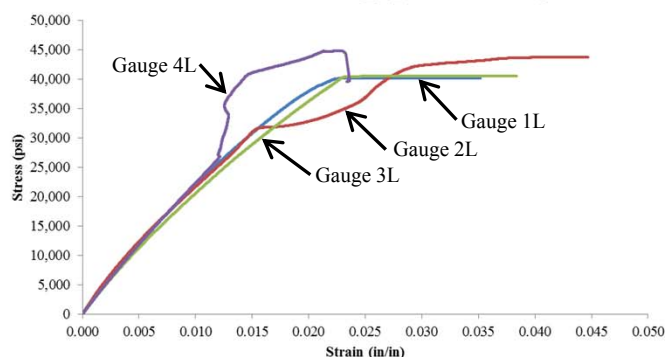
PICTURE OF SPECIMEN POST-TEST



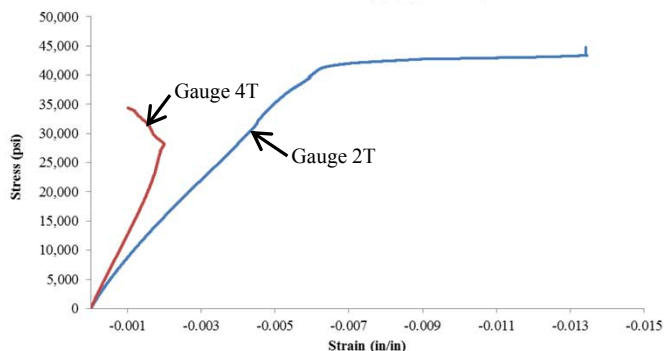
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0102 | 0.0036 | 2,033,716 | | | | |
| 2L | 0.0104 | 0.0034 | 1,923,286 | 2T | -0.0031 | -0.0010 | 0.2904 |
| 3L | 0.0111 | 0.0039 | 1,867,489 | | | | |
| 4L | 0.0100 | 0.0037 | 2,122,341 | 4T | -0.0017 | -0.0007 | 0.1571 |
| Average | | | 1,986,708 | | | | 0.2237 |

Stress-Strain Curve 70_3_(09-01), Long.



Stress-Strain Curve 70_3_(09-01), Lat.



Engineering Test Notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-4-70-FY09**
 Test Date: 1/11/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 23,130 lbs
 Tensile Strength, ST_x : 44,084 psi
 Tensile Modulus, E_x : 2,051,203 psi
 Ultimate Strain, ϵ_x : 0.0215 in/in
 Poisson's Ratio, v_{xy} : 0.1621

Measured Specimen Dimensions:

Width, W: 0.4968 in
 Thickness, H: 1.0561 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM, SMV
 20% Max Load: 4,626 lbs
 50% Max Load: 11,565 lbs

PICTURE OF SPECIMEN PRE-TEST



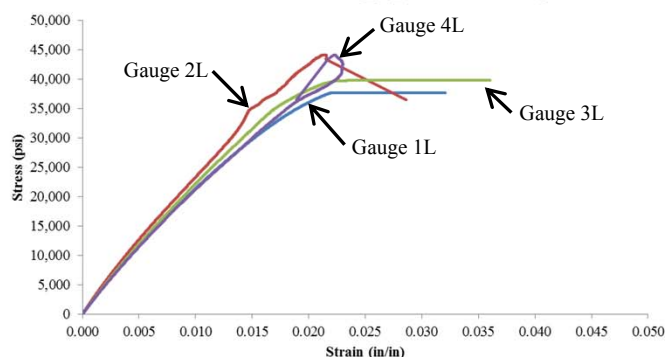
PICTURE OF SPECIMEN POST-TEST



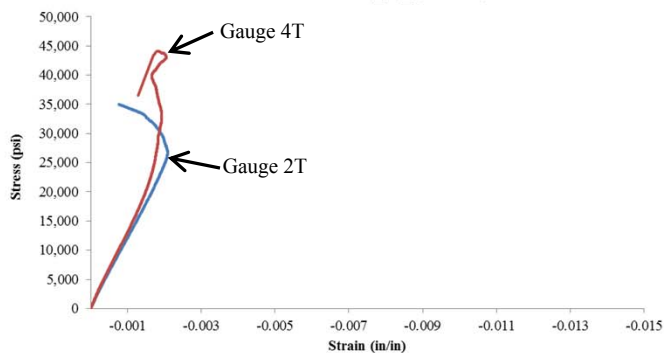
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0104 | 0.0036 | 1,958,174 | | | | |
| 2L | 0.0094 | 0.0033 | 2,183,711 | 2T | -0.0018 | -0.0007 | 0.1825 |
| 3L | 0.0099 | 0.0036 | 2,091,495 | | | | |
| 4L | 0.0105 | 0.0038 | 1,971,430 | 4T | -0.0016 | -0.0007 | 0.1417 |
| Average | | | 2,051,203 | | | | 0.1621 |

Stress-Strain Curve 70_4_(09-01), Long.



Stress-Strain Curve 70_4_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-70-FY09**
 Test Date: 1/11/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

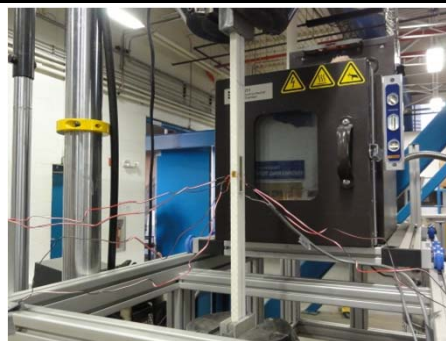
Average Material Properties:

Ultimate Load, P_x : 23,534 lbs
 Tensile Strength, ST_x : 44,173 psi
 Tensile Modulus, E_x : 2,082,773 psi
 Ultimate Strain, ϵ_x : 0.0212 in/in
 Poisson's Ratio, v_{xy} : 0.2124

Measured Specimen Dimensions:

Width, W: 0.4983 in
 Thickness, H: 1.0692 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM, SMV
 20% Max Load: 4,707 lbs
 50% Max Load: 11,767 lbs

PICTURE OF SPECIMEN PRE-TEST



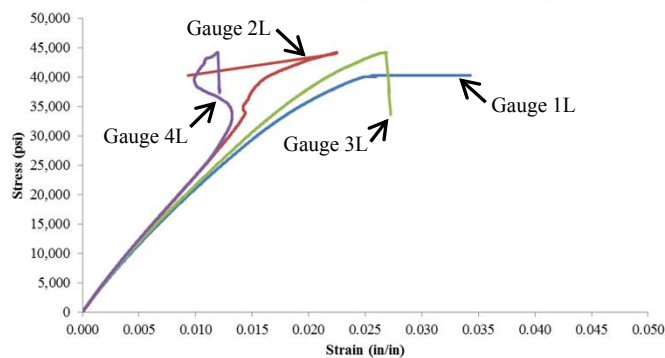
PICTURE OF SPECIMEN POST-TEST



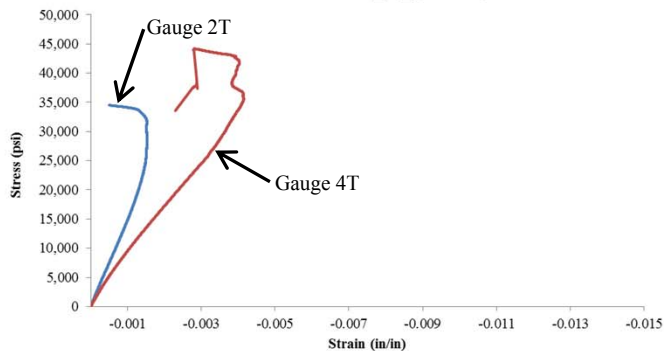
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0106 | 0.0037 | 1,921,286 | | | | |
| 2L | 0.0095 | 0.0035 | 2,224,801 | 2T | -0.0014 | -0.0006 | 0.1341 |
| 3L | 0.0103 | 0.0036 | 1,982,370 | | | | |
| 4L | 0.0095 | 0.0035 | 2,202,634 | 4T | -0.0027 | -0.0009 | 0.2906 |
| Average | | | 2,082,773 | | | | 0.2124 |

Stress-Strain Curve 70_5_(09-01), Long.



Stress-Strain Curve 70_5_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

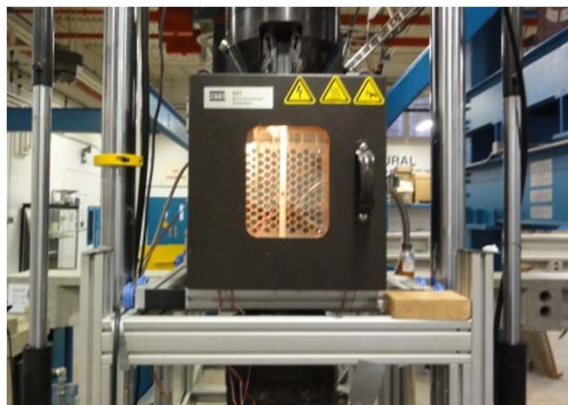
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-TX-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **ST_x , E_x , ν_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : **16,396** **lbs**
 Tensile Strength, ST_x : **33,951** **psi**
 Tensile Modulus, E_x : **1,528,496** **psi**
 Ultimate Strain, ϵ_x : **0.0226** **in/in**
 Poisson's Ratio, ν_{xy} : **0.2677**

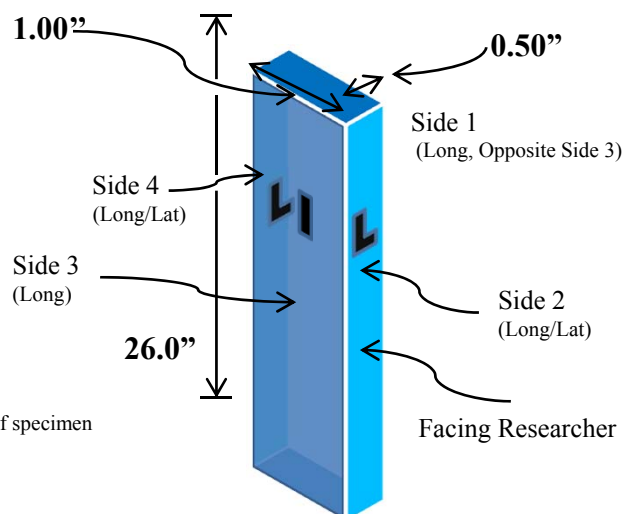
| Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-------------------------------|-----------------------------------|---------------------------------|--|-----------------------------|--------------|
| MAT1-TX-1-140-FY09 | 17,035 | 36,531 | 1,254,774 | 0.0291 | 0.1368 | DGM |
| MAT1-TX-2-140-FY09 | 16,136 | 32,819 | 1,408,796 | 0.0233 | 0.1527 | DGM |
| MAT1-TX-3-140-FY09 | 16,519 | 35,161 | 1,525,339 | 0.0231 | 0.4248 | DGM |
| MAT1-TX-4-140-FY09 | 16,326 | 35,134 | 1,758,753 | 0.0200 | 0.1362 | DGM |
| MAT1-TX-5-140-FY09 | 15,963 | 30,108 | 1,694,818 | 0.0178 | 0.4879 | DGM |
| Average | 16,396 | 33,951 | 1,528,496 | 0.0226 | 0.2677 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See D-14 to D-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-40% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-1-140-FY09**
 Test Date: 1/12/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 17,035 lbs
 Tensile Strength, ST_x : 36,531 psi
 Tensile Modulus, E_x : 1,254,774 psi
 Ultimate Strain, ϵ_x : 0.0291 in/in
 Poisson's Ratio, v_{xy} : 0.1368

Measured Specimen Dimensions:

Width, W: 0.4982 in
 Thickness, H: 0.9360 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 1,704 lbs
 40% Max Load: 6,814 lbs

PICTURE OF SPECIMEN PRE-TEST



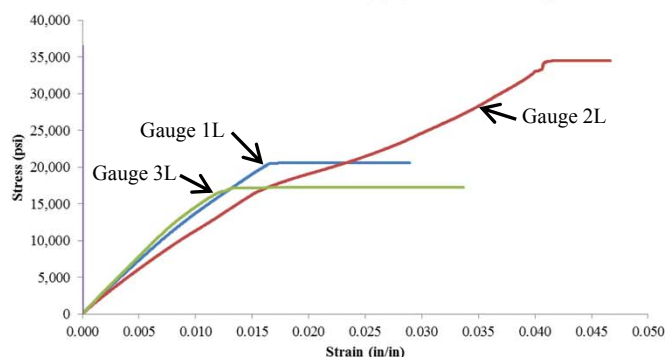
PICTURE OF SPECIMEN POST-TEST



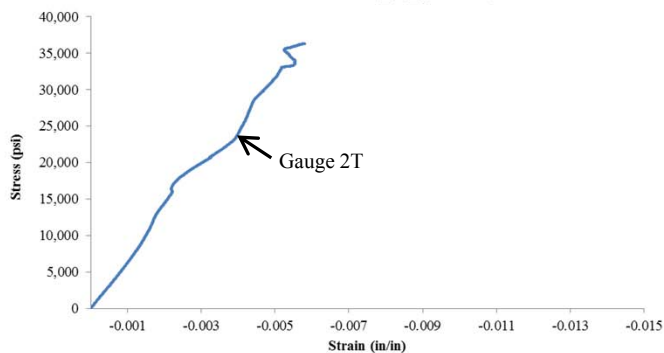
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0108 | 0.0024 | 1,304,757 | | | | |
| 2L | 0.0133 | 0.0028 | 1,043,986 | 2T | -0.0020 | -0.0006 | 0.1368 |
| 3L | 0.0100 | 0.0023 | 1,415,579 | | | | |
| 4L | Lost Gauge | | | 4T | Lost Gauge | | - |
| Average | | | 1,254,774 | | | | 0.1368 |

Stress-Strain Curve 140_1_(09-01), Long.



Stress-Strain Curve 140_1_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-2-140-FY09**
 Test Date: 1/13/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,136 lbs
 Tensile Strength, ST_x : 32,819 psi
 Tensile Modulus, E_x : 1,408,796 psi
 Ultimate Strain, ϵ_x : 0.0233 in/in
 Poisson's Ratio, ν_{xy} : 0.1527

Measured Specimen Dimensions:

Width, W: 0.4972 in
 Thickness, H: 0.9889 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 1,614 lbs
 40% Max Load: 6,454 lbs

PICTURE OF SPECIMEN PRE-TEST



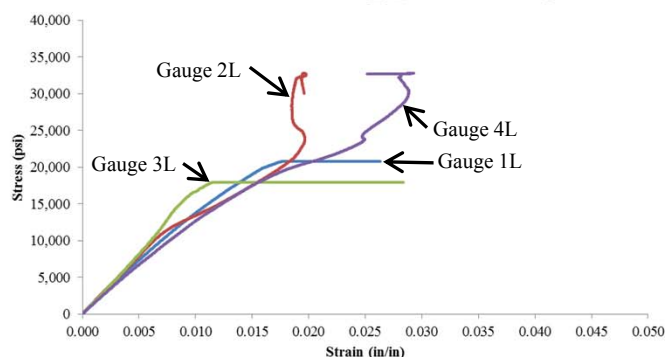
PICTURE OF SPECIMEN POST-TEST



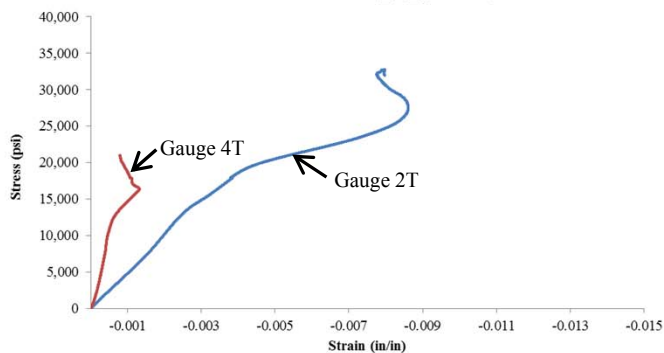
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0095 | 0.0021 | 1,344,579 | | | | |
| 2L | 0.0096 | 0.0020 | 1,302,571 | 2T | -0.0025 | -0.0007 | 0.2435 |
| 3L | 0.0076 | 0.0021 | 1,769,507 | | | | |
| 4L | 0.0104 | 0.0023 | 1,218,525 | 4T | -0.0007 | -0.0002 | 0.0618 |
| Average | | | 1,408,796 | | | | 0.1527 |

Stress-Strain Curve 140_2_(09-01), Long.



Stress-Strain Curve 140_2_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-3-140-FY09**
 Test Date: 1/13/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,519 lbs
 Tensile Strength, ST_x : 35,161 psi
 Tensile Modulus, E_x : 1,525,339 psi
 Ultimate Strain, ϵ_x : 0.0231 in/in
 Poisson's Ratio, v_{xy} : 0.4248

Measured Specimen Dimensions:

Width, W: 0.4992 in
 Thickness, H: 0.9411 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 1,652 lbs
 40% Max Load: 6,607 lbs

PICTURE OF SPECIMEN PRE-TEST



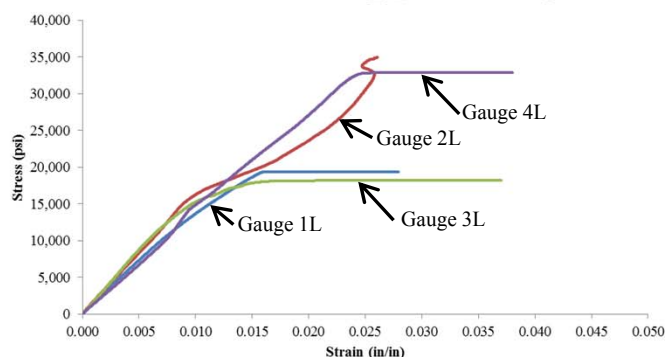
PICTURE OF SPECIMEN POST-TEST



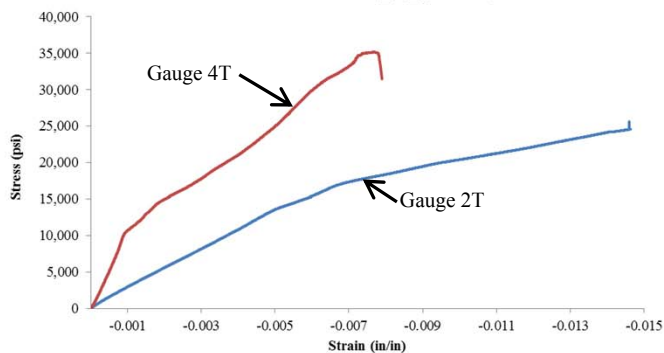
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0104 | 0.0023 | 1,307,571 | | | | |
| 2L | 0.0083 | 0.0020 | 1,676,364 | 2T | -0.0053 | -0.0012 | 0.6457 |
| 3L | 0.0088 | 0.0020 | 1,553,900 | | | | |
| 4L | 0.0094 | 0.0026 | 1,563,523 | 4T | -0.0017 | -0.0004 | 0.2039 |
| Average | | | 1,525,339 | | | | 0.4248 |

Stress-Strain Curve 140_3_(09-01), Long.



Stress-Strain Curve 140_3_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-4-140-FY09**
 Test Date: 1/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,326 lbs
 Tensile Strength, ST_x : 35,134 psi
 Tensile Modulus, E_x : 1,758,753 psi
 Ultimate Strain, ϵ_x : 0.0200 in/in
 Poisson's Ratio, v_{xy} : 0.1362

Measured Specimen Dimensions:

Width, W: 0.4963 in
 Thickness, H: 0.9363 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 1,633 lbs
 40% Max Load: 6,530 lbs

PICTURE OF SPECIMEN PRE-TEST



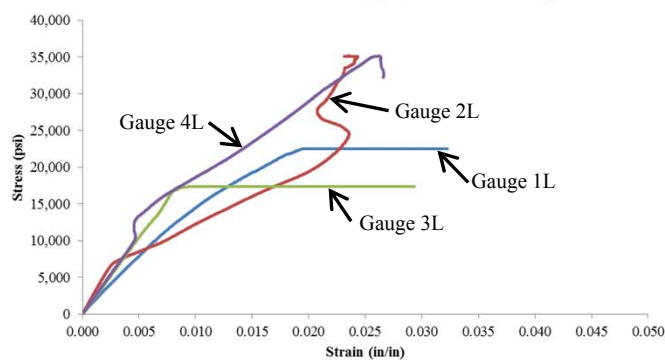
PICTURE OF SPECIMEN POST-TEST



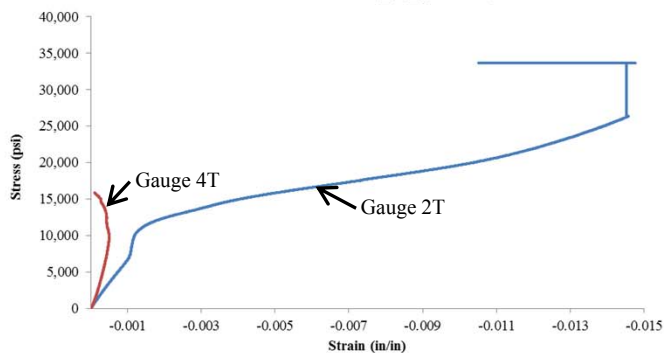
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0096 | 0.0021 | 1,399,165 | | | | |
| 2L | 0.0124 | 0.0013 | 949,491 | 2T | -0.0032 | -0.0005 | 0.2467 |
| 3L | 0.0069 | 0.0017 | 2,025,956 | | | | |
| 4L | 0.0056 | 0.0016 | 2,660,402 | 4T | -0.0003 | -0.0002 | 0.0256 |
| Average | | | 1,758,753 | | | | 0.1362 |

Stress-Strain Curve 140_4_(09-01), Long.



Stress-Strain Curve 140_4_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT1-TX-5-140-FY09**
 Test Date: 1/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 15,963 lbs
 Tensile Strength, ST_x : 30,108 psi
 Tensile Modulus, E_x : 1,694,818 psi
 Ultimate Strain, ϵ_x : 0.0178 in/in
 Poisson's Ratio, ν_{xy} : 0.4879

Measured Specimen Dimensions:

Width, W: 0.4992 in
 Thickness, H: 1.0621 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 10% Max Load: 1,596 lbs
 40% Max Load: 6,385 lbs

PICTURE OF SPECIMEN PRE-TEST



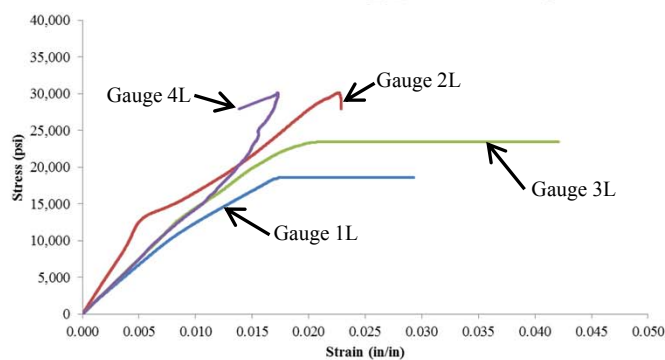
PICTURE OF SPECIMEN POST-TEST



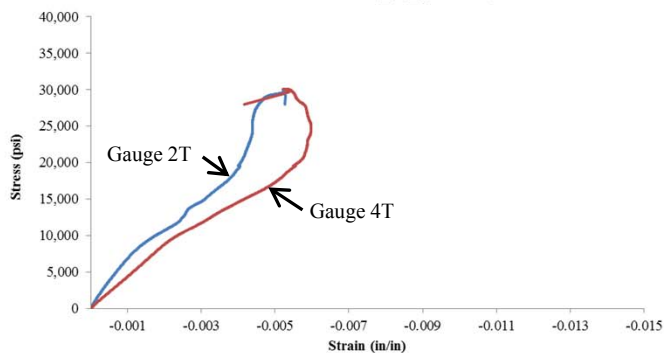
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 40% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0096 | 0.0021 | 1,209,516 | | | | |
| 2L | 0.0048 | 0.0012 | 2,569,674 | 2T | -0.0024 | -0.0004 | 0.5784 |
| 3L | 0.0079 | 0.0020 | 1,521,983 | | | | |
| 4L | 0.0081 | 0.0020 | 1,478,097 | 4T | -0.0031 | -0.0007 | 0.3974 |
| Average | | | 1,694,818 | | | | 0.4879 |

Stress-Strain Curve 140_5_(09-01), Long.



Stress-Strain Curve 140_5_(09-01), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-N40-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 38,032 lbs
 Compressive Strength, SC_x : 39,116 psi
 Compressive Modulus, E_x : 2,877,581 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.253

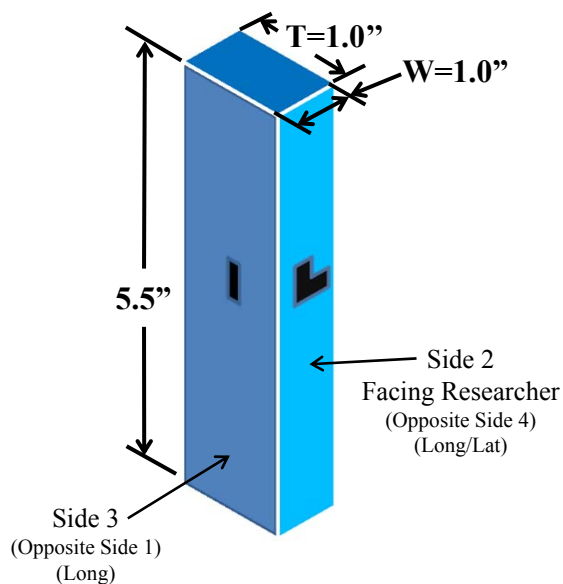
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT1- CX-01-N40-FY09 | 38,509 | 38,902 | 2,831,357 | 0.014 | 0.240 | Delamination |
| MAT1- CX-02-N40-FY09 | 35,470 | 36,944 | 2,993,387 | 0.013 | 0.243 | Delamination |
| MAT1- CX-03-N40-FY09 | 39,109 | 40,734 | 3,043,342 | 0.014 | 0.214 | Delamination |
| MAT1- CX-04-N40-FY09 | 39,216 | 39,911 | 2,748,102 | 0.015 | 0.327 | Delamination |
| MAT1- CX-05-N40-FY09 | 37,858 | 39,089 | 2,771,719 | 0.014 | 0.242 | Delamination |
| Average | 38,032 | 39,116 | 2,877,581 | 0.014 | 0.253 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See D-20 to D-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-01-N40-FY09**
 Test Date: 8/24/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 38,509 lbs
 Compressive Strength, SC_x : 38,902 psi
 Compressive Modulus, E_x : 2,831,357 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.240

Measured Specimen Dimensions:

Width, W: 1.0330 in
 Thickness, H: 0.9583 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,702 lbs
 50% Max Load: 19,255 lbs

PICTURE OF SPECIMEN PRE-TEST



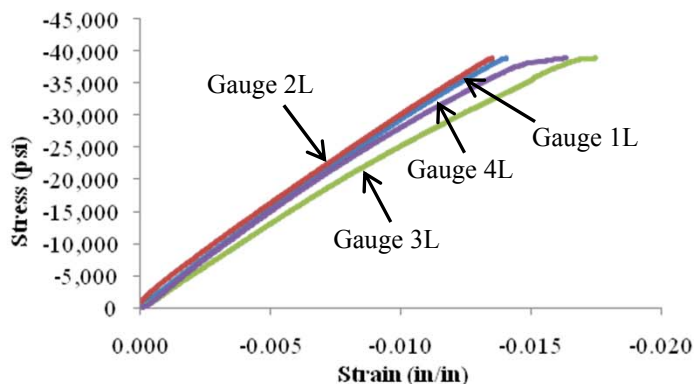
PICTURE OF SPECIMEN POST-TEST



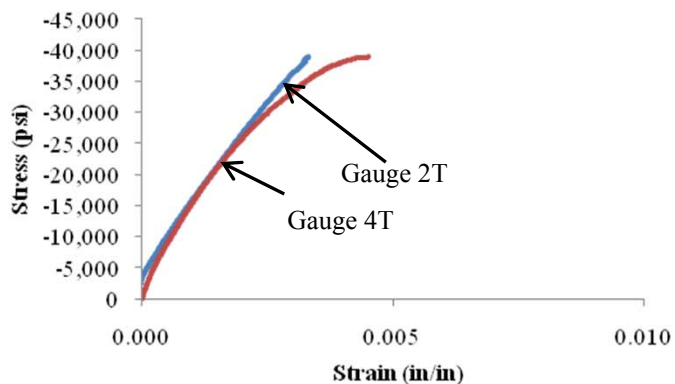
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00641 | -0.00243 | 2,932,331 | | | | |
| 2L | -0.00609 | -0.00207 | 2,901,869 | 2T | 0.00132 | 0.00032 | 0.250 |
| 3L | -0.00749 | -0.00300 | 2,601,108 | | | | |
| 4L | -0.00657 | -0.00253 | 2,890,120 | 4T | 0.00135 | 0.00042 | 0.229 |
| Average | | | 2,831,357 | | | | 0.240 |

Stress-Strain Curve N40_01_(09-01)_Long



Stress-Strain Curve N40_01_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-02-N40-FY09**
 Test Date: 8/24/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 35,470 lbs
 Compressive Strength, SC_x : 36,944 psi
 Compressive Modulus, E_x : 2,993,387 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, v_{xy} : 0.243

Measured Specimen Dimensions:

Width, W: 1.0037 in
 Thickness, H: 0.9566 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,094 lbs
 50% Max Load: 17,735 lbs

PICTURE OF SPECIMEN PRE-TEST



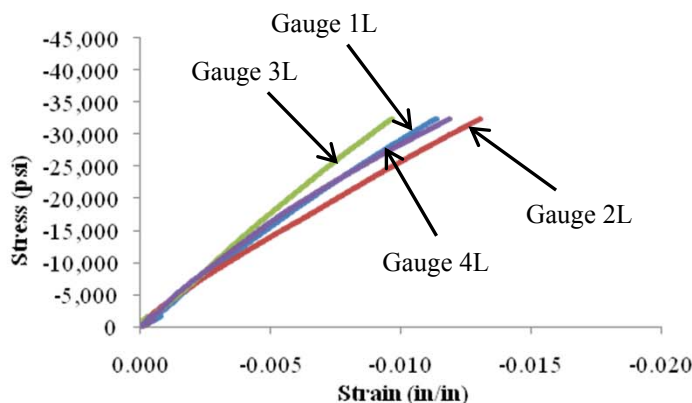
PICTURE OF SPECIMEN POST-TEST



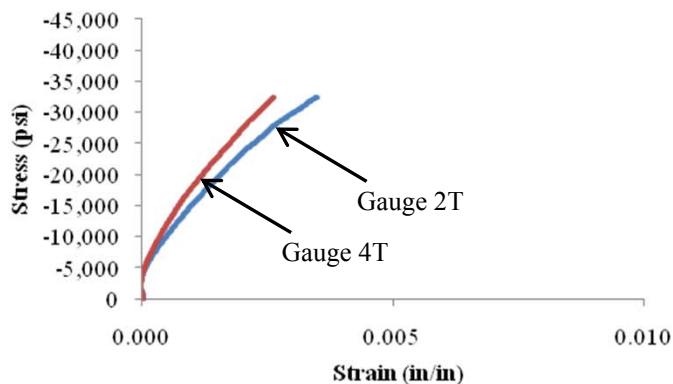
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00599 | -0.00225 | 2,964,718 | | | | |
| 2L | -0.00690 | -0.00234 | 2,428,898 | 2T | 0.00138 | 0.00024 | 0.250 |
| 3L | -0.00523 | -0.00214 | 3,589,053 | | | | |
| 4L | -0.00578 | -0.00207 | 2,990,878 | 4T | 0.00105 | 0.00018 | 0.235 |
| Average | | | 2,993,387 | | | | 0.243 |

Stress-Strain Curve N40_02_(09-01)_Long



Stress-Strain Curve N40_02_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-03-N40-FY09**
 Test Date: 8/24/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 39,109 lbs
 Compressive Strength, SC_x : 40,734 psi
 Compressive Modulus, E_x : 3,043,342 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.214

Measured Specimen Dimensions:

Width, W: 1.0271 in
 Thickness, H: 0.9543 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,822 lbs
 50% Max Load: 19,554 lbs

PICTURE OF SPECIMEN PRE-TEST



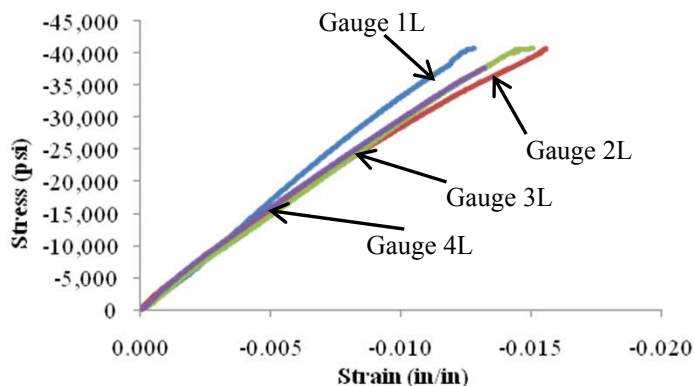
PICTURE OF SPECIMEN POST-TEST



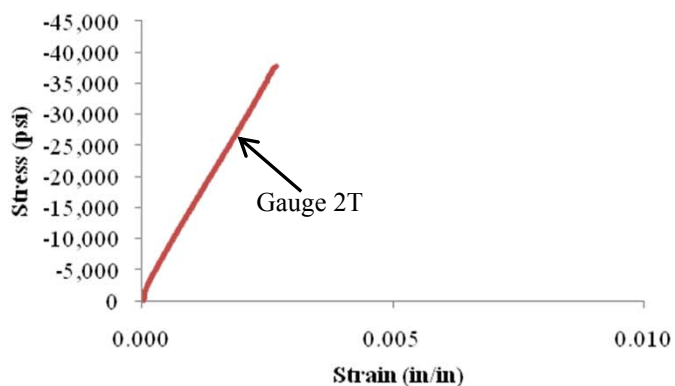
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00596 | -0.00260 | 3,634,405 | | | | |
| 2L | -0.00682 | -0.00246 | 2,797,207 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00694 | -0.00264 | 2,843,315 | | | | |
| 4L | -0.00657 | -0.00236 | 2,898,442 | 4T | 0.00139 | 0.00049 | 0.214 |
| Average | | | 3,043,342 | | | | 0.214 |

Stress-Strain Curve N40_03_(09-01)_Long



Stress-Strain Curve N40_03_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-04-N40-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 39,216 lbs
 Compressive Strength, SC_x : 39,911 psi
 Compressive Modulus, E_x : 2,748,102 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.327

Measured Specimen Dimensions:

Width, W: 1.0224 in
 Thickness, H: 0.9611 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,843 lbs
 50% Max Load: 19,608 lbs

PICTURE OF SPECIMEN PRE-TEST



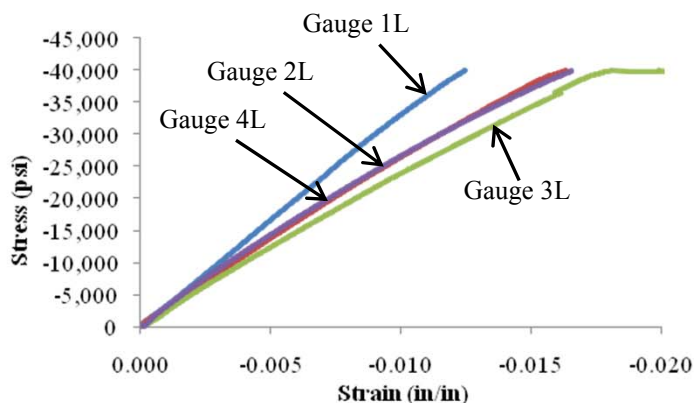
PICTURE OF SPECIMEN POST-TEST



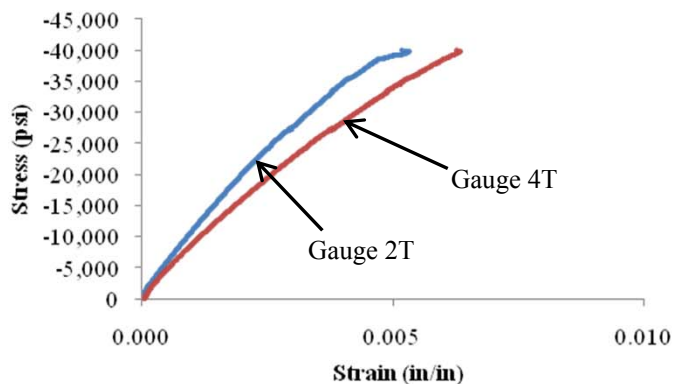
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00598 | -0.00242 | 3,368,047 | | | | |
| 2L | -0.00735 | -0.00284 | 2,654,558 | 2T | 0.00198 | 0.00070 | 0.285 |
| 3L | -0.00822 | -0.00314 | 2,353,184 | | | | |
| 4L | -0.00720 | -0.00262 | 2,616,620 | 4T | 0.00258 | 0.00089 | 0.369 |
| Average | | | 2,748,102 | | | | 0.327 |

Stress-Strain Curve N40_04_(09-01)_Long



Stress-Strain Curve N40_04_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-05-N40-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 37,858 lbs
 Compressive Strength, SC_x : 39,089 psi
 Compressive Modulus, E_x : 2,771,719 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.242

Measured Specimen Dimensions:

Width, W: 1.0134 in
 Thickness, H: 0.9557 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,572 lbs
 50% Max Load: 18,929 lbs

PICTURE OF SPECIMEN PRE-TEST



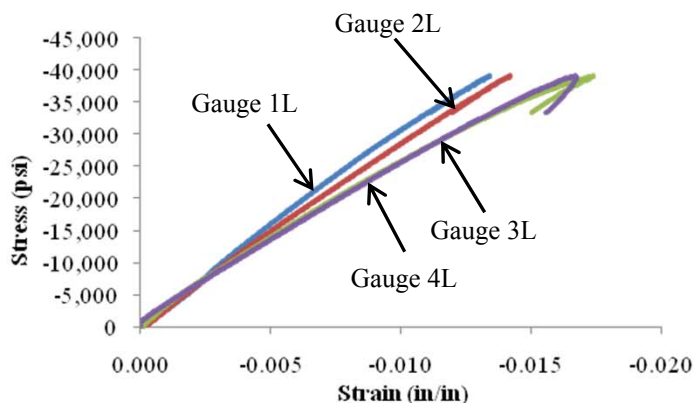
PICTURE OF SPECIMEN POST-TEST



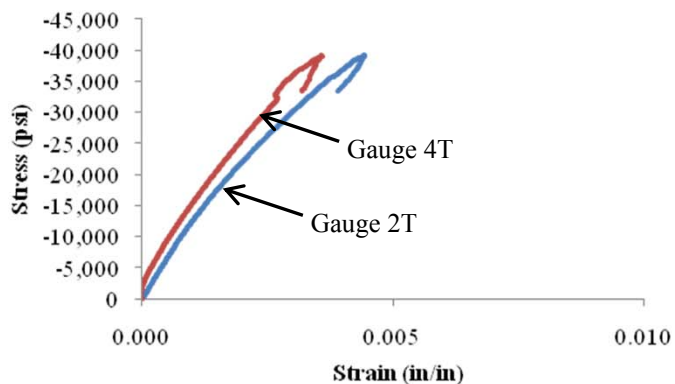
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00614 | -0.00253 | 3,245,625 | | | | |
| 2L | -0.00668 | -0.00261 | 2,884,517 | 2T | 0.00172 | 0.00107 | 0.274 |
| 3L | -0.00728 | -0.00259 | 2,502,151 | | | | |
| 4L | -0.00744 | -0.00266 | 2,454,581 | 4T | 0.00139 | 0.00039 | 0.211 |
| Average | | | 2,771,719 | | | | 0.242 |

Stress-Strain Curve N40_05_(09-01)_Long



Stress-Strain Curve N40_05_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

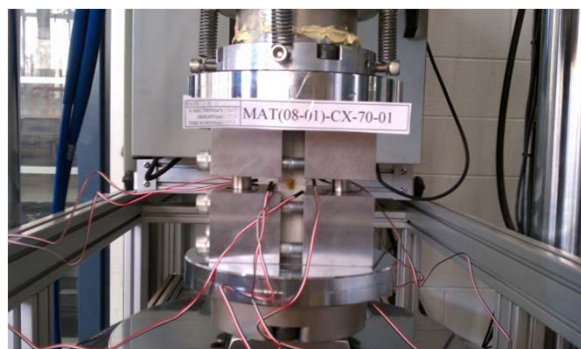
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-70-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 26,057 lbs
 Compressive Strength, SC_x : 26,453 psi
 Compressive Modulus, E_x : 2,796,012 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.262

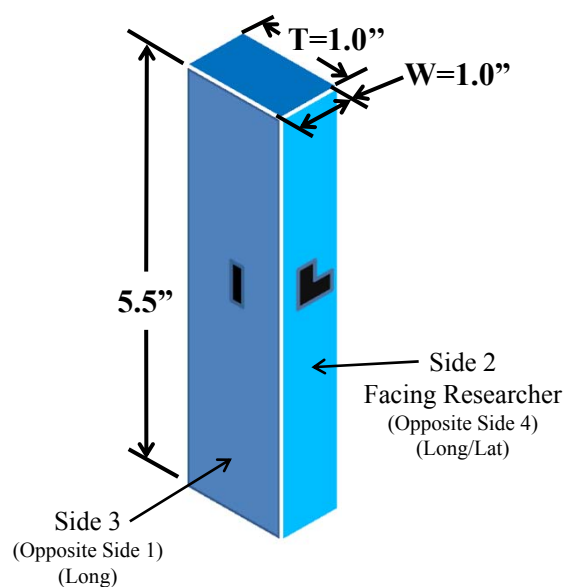
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT1-CX-01-70-FY09 | 29,007 | 27,875 | 2,876,870 | 0.010 | 0.163 | Delamination |
| MAT1-CX-02-70-FY09 | 26,207 | 27,046 | 2,747,493 | 0.010 | 0.243 | Delamination |
| MAT1-CX-03-70-FY09 | 21,419 | 23,491 | 2,826,270 | 0.009 | 0.351 | Delamination |
| MAT1-CX-04-70-FY09 | 26,870 | 26,905 | 2,730,568 | 0.010 | 0.272 | Delamination |
| MAT1-CX-05-70-FY09 | 26,782 | 26,949 | 2,798,858 | 0.010 | 0.280 | Delamination |
| Average | 26,057 | 26,453 | 2,796,012 | 0.010 | 0.262 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See D-26 to D-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-01-70-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 29,007 lbs
 Compressive Strength, SC_x : 27,875 psi
 Compressive Modulus, E_x : 2,876,870 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.163

Measured Specimen Dimensions:

Width, W: 1.0885 in
 Thickness, H: 0.9560 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,801 lbs
 50% Max Load: 14,504 lbs

PICTURE OF SPECIMEN PRE-TEST



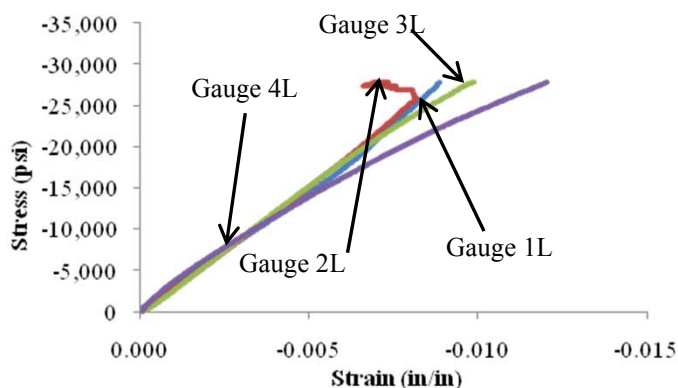
PICTURE OF SPECIMEN POST-TEST



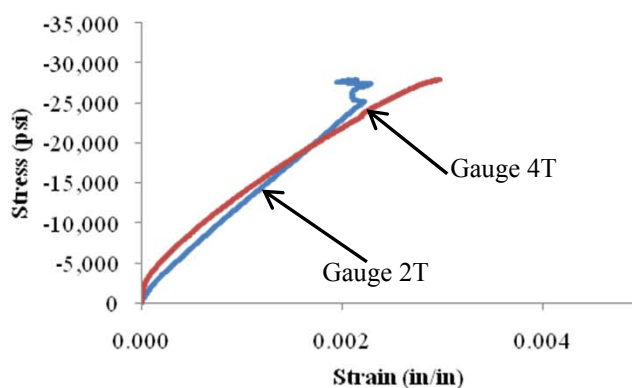
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00486 | -0.00180 | 2,737,006 | | | | |
| 2L | -0.00462 | -0.00193 | 3,106,372 | 2T | 0.00114 | 0.00038 | 0.165 |
| 3L | -0.00457 | -0.00193 | 3,166,192 | | | | |
| 4L | -0.00498 | -0.00163 | 2,497,908 | 4T | 0.00102 | 0.00022 | 0.160 |
| Average | | | 2,876,870 | | | | 0.163 |

Stress-Strain Curve 70F_01_(09-01)_Long



Stress-Strain Curve 70F_01_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-02-70-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 26,207 lbs
 Compressive Strength, SC_x : 27,046 psi
 Compressive Modulus, E_x : 2,747,493 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : 0.243

Measured Specimen Dimensions:

Width, W: 1.0149 in
 Thickness, H: 0.9548 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,241 lbs
 50% Max Load: 13,104 lbs

PICTURE OF SPECIMEN PRE-TEST



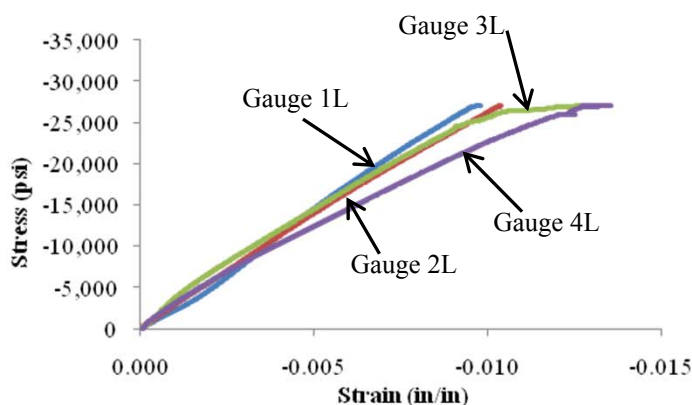
PICTURE OF SPECIMEN POST-TEST



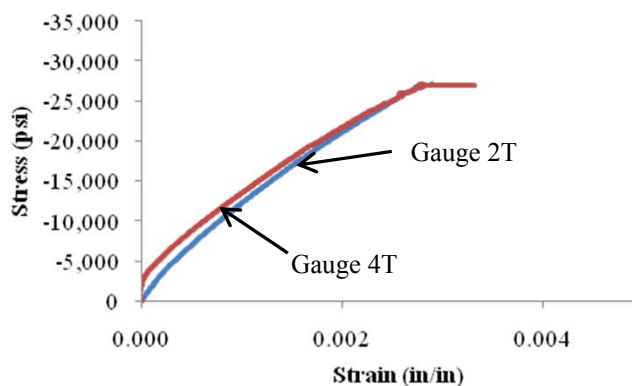
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00465 | -0.00222 | 3,338,290 | | | | |
| 2L | -0.00480 | -0.00190 | 2,795,139 | 2T | 0.00113 | 0.00036 | 0.265 |
| 3L | -0.00460 | -0.00151 | 2,624,343 | | | | |
| 4L | -0.00551 | -0.00187 | 2,232,200 | 4T | 0.00100 | 0.00019 | 0.221 |
| Average | | | 2,747,493 | | | | 0.243 |

Stress-Strain Curve 70F_02_(09-01)_Long



Stress-Strain Curve 70F_02_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-03-70-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 21,419 lbs
 Compressive Strength, SC_x : 23,491 psi
 Compressive Modulus, E_x : 2,826,270 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.351

Measured Specimen Dimensions:

Width, W : 0.9548 in
 Thickness, H : 0.9550 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,284 lbs
 50% Max Load: 10,710 lbs

PICTURE OF SPECIMEN PRE-TEST



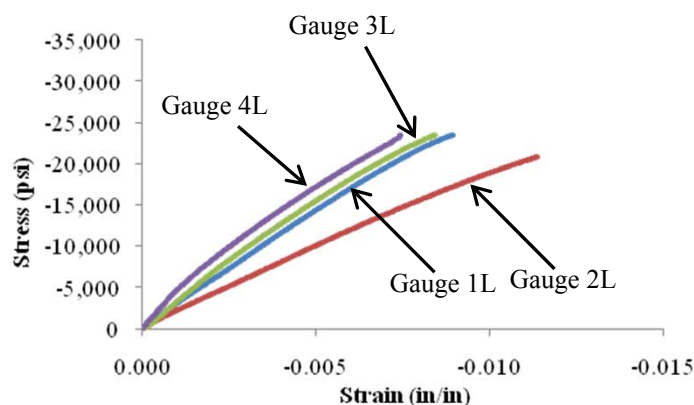
PICTURE OF SPECIMEN POST-TEST



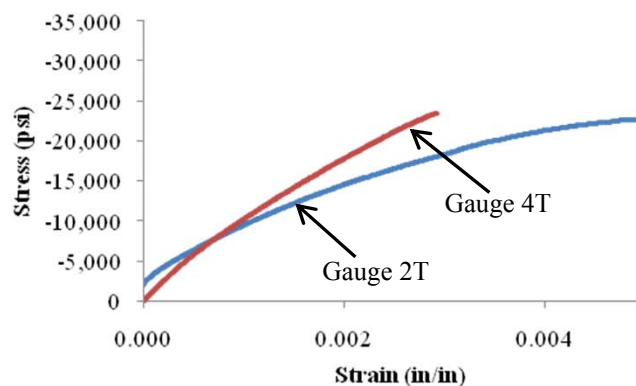
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00403 | -0.00154 | 2,829,733 | | | | |
| 2L | -0.00584 | -0.00225 | 1,961,357 | 2T | 0.00141 | 0.00025 | 0.321 |
| 3L | -0.00364 | -0.00139 | 3,128,681 | | | | |
| 4L | -0.00307 | -0.00099 | 3,385,309 | 4T | 0.00118 | 0.00039 | 0.381 |
| Average | | | 2,826,270 | | | | 0.351 |

Stress-Strain Curve 70F_03_(09-01)_Long



Stress-Strain Curve 70F_03_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-04-70-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 26,870 lbs
 Compressive Strength, SC_x : 26,905 psi
 Compressive Modulus, E_x : 2,730,568 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.272

Measured Specimen Dimensions:

Width, W: 1.0303 in
 Thickness, H: 0.9693 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,374 lbs
 50% Max Load: 13,435 lbs

PICTURE OF SPECIMEN PRE-TEST



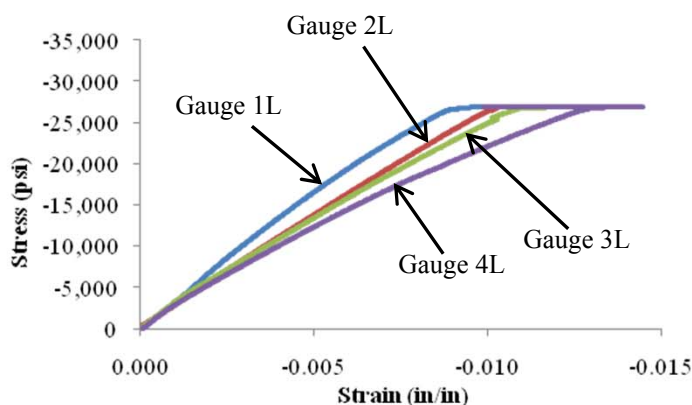
PICTURE OF SPECIMEN POST-TEST



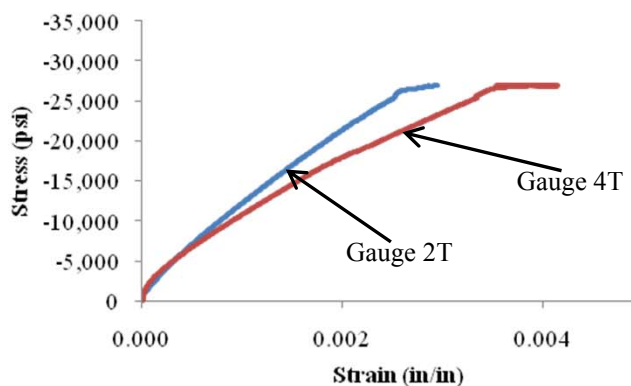
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00398 | -0.00160 | 3,399,699 | | | | |
| 2L | -0.00484 | -0.00187 | 2,719,343 | 2T | 0.00112 | 0.00035 | 0.261 |
| 3L | -0.00499 | -0.00177 | 2,503,328 | | | | |
| 4L | -0.00549 | -0.00198 | 2,299,900 | 4T | 0.00134 | 0.00035 | 0.283 |
| Average | | | 2,730,568 | | | | 0.272 |

Stress-Strain Curve 70F_04_(09-01)_Long



Stress-Strain Curve 70F_04_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-05-70-FY09**
 Test Date: 8/31/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 26,782 lbs
 Compressive Strength, SC_x : 26,949 psi
 Compressive Modulus, E_x : 2,798,858 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.280

Measured Specimen Dimensions:

Width, W: 1.0385 in
 Thickness, H: 0.9570 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,356 lbs
 50% Max Load: 13,391 lbs

PICTURE OF SPECIMEN PRE-TEST



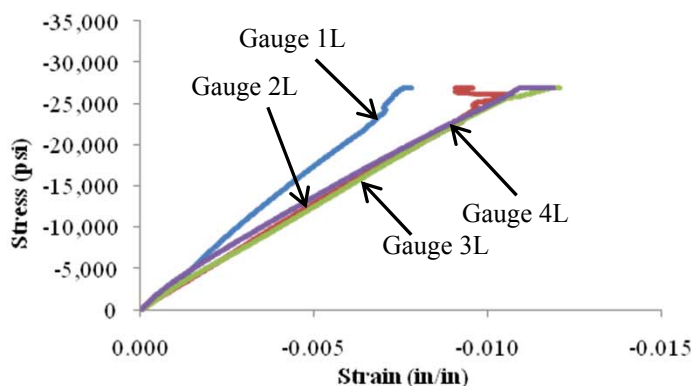
PICTURE OF SPECIMEN POST-TEST



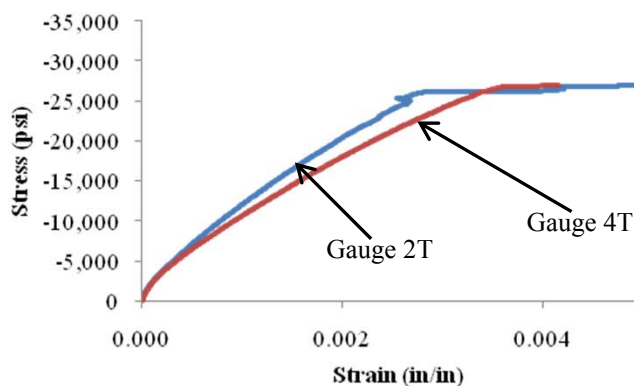
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00378 | -0.00159 | 3,702,737 | | | | |
| 2L | -0.00522 | -0.00208 | 2,574,141 | 2T | 0.00115 | 0.00035 | 0.257 |
| 3L | -0.00538 | -0.00205 | 2,430,743 | | | | |
| 4L | -0.00490 | -0.00165 | 2,487,809 | 4T | 0.00136 | 0.00038 | 0.303 |
| Average | | | 2,798,858 | | | | 0.280 |

Stress-Strain Curve 70F_05_(09-01)_Long



Stress-Strain Curve 70F_05_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CX-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 11,269 lbs
 Compressive Strength, SC_x : 11,890 psi
 Compressive Modulus, E_x : 2,298,9234 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.298

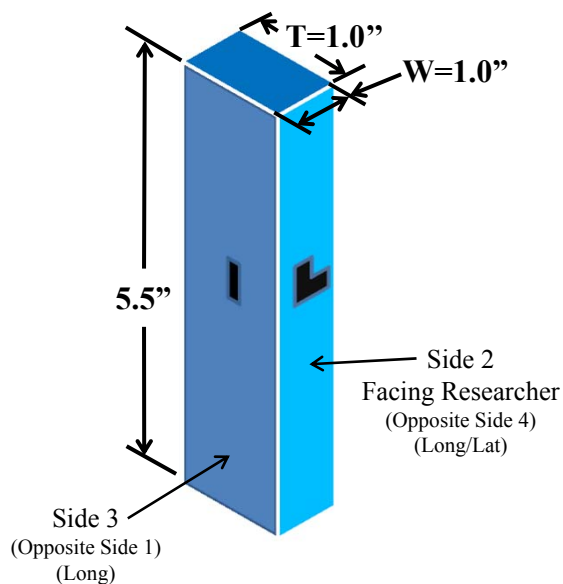
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT1-CX-01-140-FY09 | 12,027 | 12,627 | 2,304,058 | 0.006 | 0.165 | Delamination |
| MAT1-CX-02-140-FY09 | 9,945 | 10,428 | 2,079,373 | 0.005 | 0.280 | Delamination |
| MAT1 CX-03-140-FY09 | 13,971 | 14,901 | 2,516,696 | 0.006 | 0.352 | Delamination |
| MAT1-CX-04-140-FY09 | 10,473 | 11,118 | 2,413,794 | 0.005 | 0.232 | Delamination |
| MAT1-CX-05-140-FY09 | 10,063 | 10,378 | 2,177,251 | 0.005 | 0.461 | Delamination |
| Average | 11,296 | 11,890 | 2,298,234 | 0.005 | 0.298 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See D-32 to D-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-01-140-FY09
 Test Date: 8/29/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

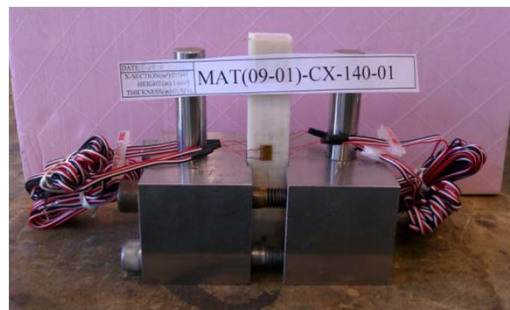
Average Material Properties:

Maximum Load, P_x : 12,027 lbs
 Compressive Strength, SC_x : 12,627 psi
 Compressive Modulus, E_x : 2,304,058 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, ν_{xy} : 0.165

Measured Specimen Dimensions:

Width, W: 1.0009 in
 Thickness, H: 0.9516 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,405 lbs
 50% Max Load: 6,013 lbs

PICTURE OF SPECIMEN PRE-TEST



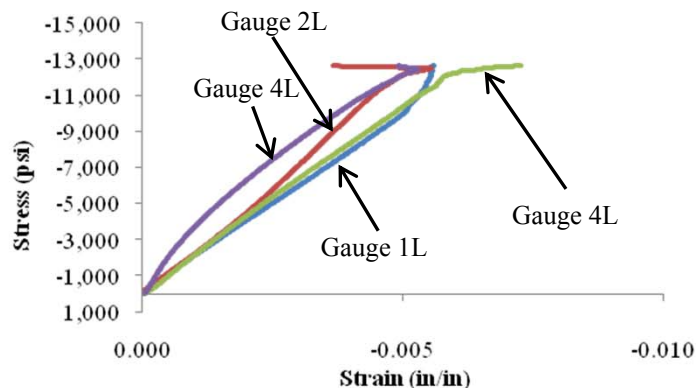
PICTURE OF SPECIMEN POST-TEST



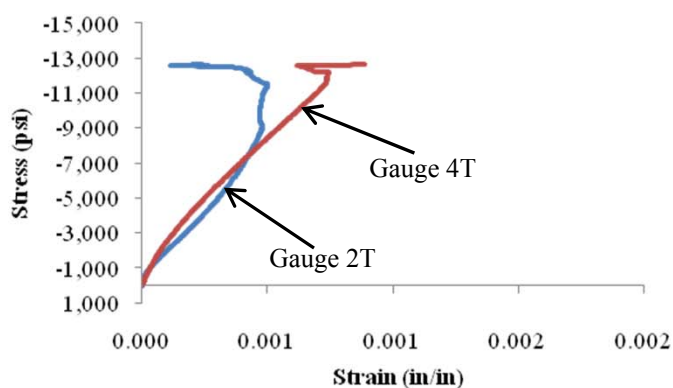
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00317 | -0.00120 | 1,921,947 | | | | |
| 2L | -0.00270 | -0.00114 | 2,430,434 | 2T | 0.00038 | 0.00014 | 0.152 |
| 3L | -0.00296 | -0.00117 | 2,112,778 | | | | |
| 4L | -0.00201 | -0.00063 | 2,751,072 | 4T | 0.00034 | 0.00010 | 0.177 |
| Average | | | 2,304,058 | | | | 0.165 |

Stress-Strain Curve 140F_01_(09-01)_Long



Stress-Strain Curve 140F_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT1-CX-02-140-FY09**
 Test Date: 8/29/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

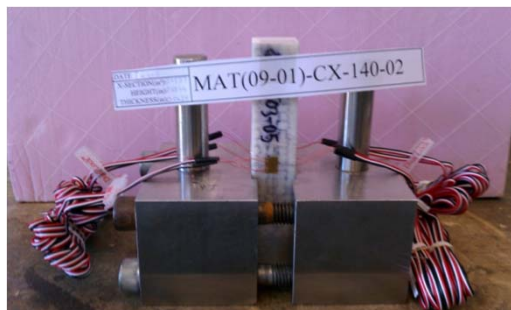
Average Material Properties:

Maximum Load, P_x : 9,945 lbs
 Compressive Strength, SC_x : 10,428 psi
 Compressive Modulus, E_x : 2,079,373 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, v_{xy} : 0.280

Measured Specimen Dimensions:

Width, W: 0.9899 in
 Thickness, H: 0.9634 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 1,989 5,799 lbs
 50% Max Load: 4,972 lbs

PICTURE OF SPECIMEN PRE-TEST



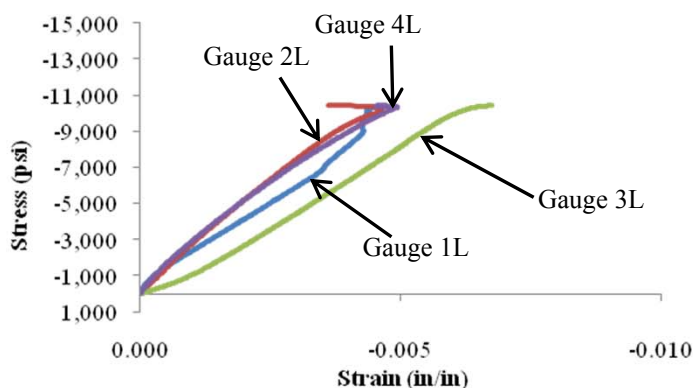
PICTURE OF SPECIMEN POST-TEST



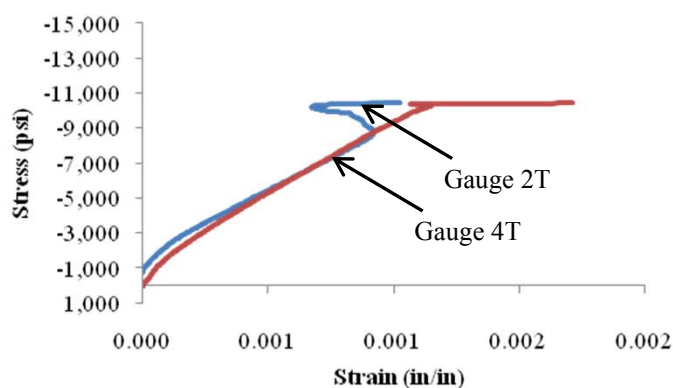
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00260 | -0.00082 | 1,762,701 | | | | |
| 2L | -0.00200 | -0.00073 | 2,460,227 | 2T | 0.00047 | 0.00008 | 0.303 |
| 3L | -0.00341 | -0.00165 | 1,773,593 | | | | |
| 4L | -0.00200 | -0.00065 | 2,320,969 | 4T | 0.00049 | 0.00049 | 0.257 |
| Average | | | 2,079,373 | | | | 0.280 |

Stress-Strain Curve 140F_02_(09-01)_Long



Stress-Strain Curve 140F_02_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-03-140-FY09
 Test Date: 8/29/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 13,971 lbs
 Compressive Strength, SC_x : 14,901 psi
 Compressive Modulus, E_x : 2,516,696 psi
 Ultimate Strain, ϵ_x : 0.006 in/in
 Poisson's Ratio, ν_{xy} : 0.352

Measured Specimen Dimensions:

Width, W: 0.9817 in
 Thickness, H: 0.9551 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,794 lbs
 50% Max Load: 6,986 lbs

PICTURE OF SPECIMEN PRE-TEST



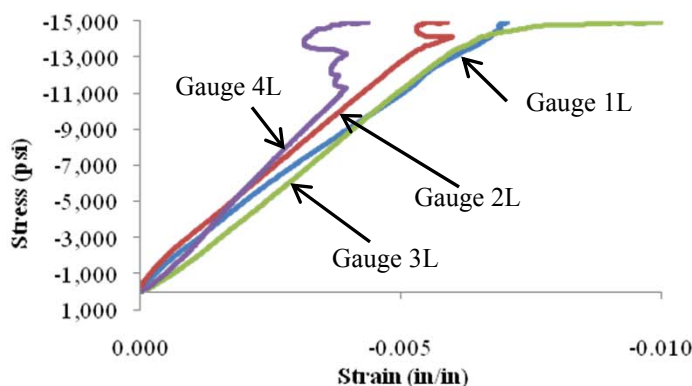
PICTURE OF SPECIMEN POST-TEST



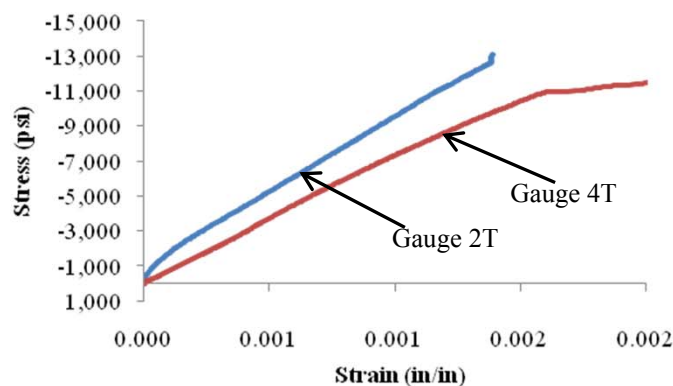
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00316 | -0.00112 | 2,191,407 | | | | |
| 2L | -0.00276 | -0.00090 | 2,393,920 | 2T | 0.00075 | 0.00023 | 0.280 |
| 3L | -0.00343 | -0.00153 | 2,350,477 | | | | |
| 4L | -0.00260 | -0.00117 | 3,130,979 | 4T | 0.00102 | 0.00041 | 0.424 |
| Average | | | 2,516,696 | | | | 0.352 |

Stress-Strain Curve 140F_03_(09-01)_Long



Stress-Strain Curve 140F_03_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-04-140-FY09
 Test Date: 8/29/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 10,473 lbs
 Compressive Strength, SC_x : 11,118 psi
 Compressive Modulus, E_x : 2,413,794 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, v_{xy} : 0.232

Measured Specimen Dimensions:

Width, W: 0.9808 in
 Thickness, H: 0.9604 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,095 lbs
 50% Max Load: 5,237 lbs

PICTURE OF SPECIMEN PRE-TEST



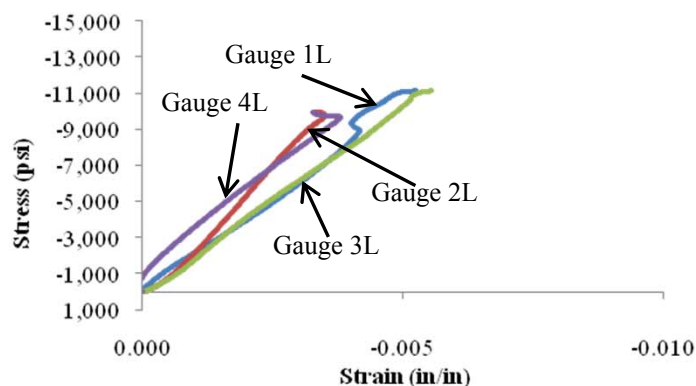
PICTURE OF SPECIMEN POST-TEST



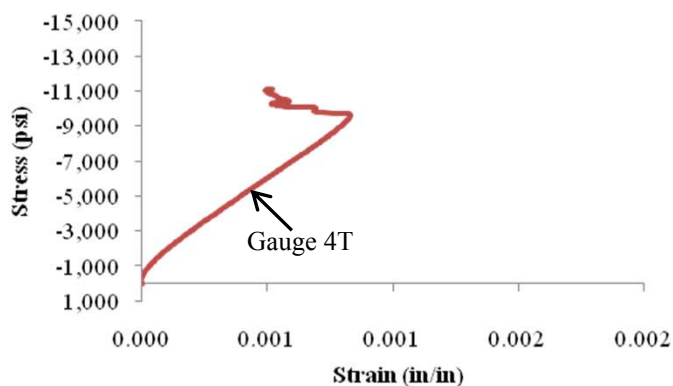
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00280 | -0.00103 | 1,889,019 | | | | |
| 2L | -0.00207 | -0.00102 | 3,198,827 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00270 | -0.00118 | 2,204,234 | | | | |
| 4L | -0.00186 | -0.00045 | 2,363,097 | 4T | 0.00045 | 0.00012 | 0.232 |
| Average | | | 2,413,794 | | | | 0.232 |

Stress-Strain Curve 140F_04_(09-01)_Long



Stress-Strain Curve 140F_04_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT1-CX-05-140-FY09
 Test Date: 8/30/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 10,063 lbs
 Compressive Strength, SC_x : 10,378 psi
 Compressive Modulus, E_x : 2,177,251 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, v_{xy} : 0.461

Measured Specimen Dimensions:

Width, W: 1.0056 in
 Thickness, H: 0.9633 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,013 lbs
 50% Max Load: 5,032 lbs

PICTURE OF SPECIMEN PRE-TEST



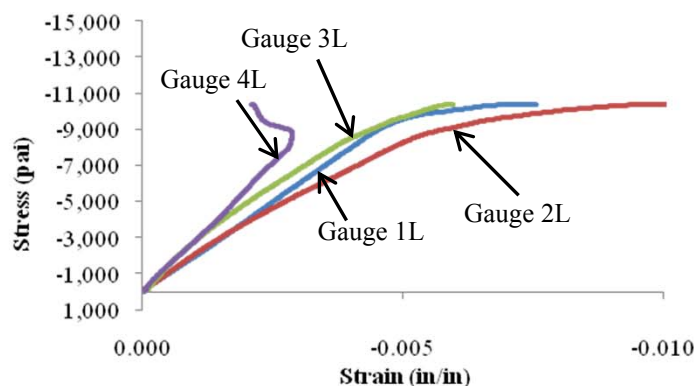
PICTURE OF SPECIMEN POST-TEST



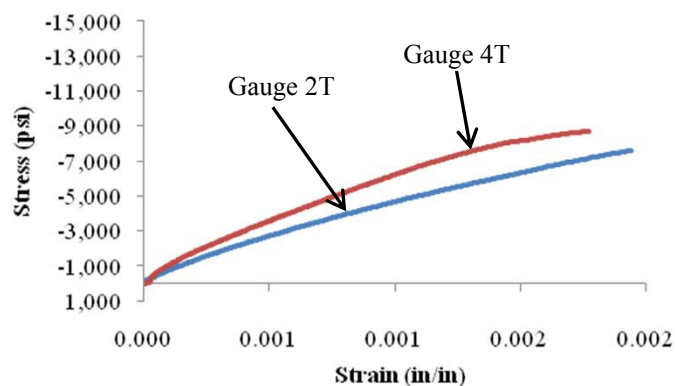
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00260 | -0.00106 | 2,033,078 | | | | |
| 2L | -0.00286 | -0.00100 | 1,675,352 | 2T | 0.00115 | 0.00035 | 0.427 |
| 3L | -0.00213 | -0.00072 | 2,200,109 | | | | |
| 4L | -0.00183 | -0.00072 | 2,800,465 | 4T | 0.00080 | 0.00024 | 0.495 |
| Average | | | 2,177,251 | | | | 0.461 |

Stress-Strain Curve 140F_05_(09-01)_Long



Stress-Strain Curve 140F_05_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

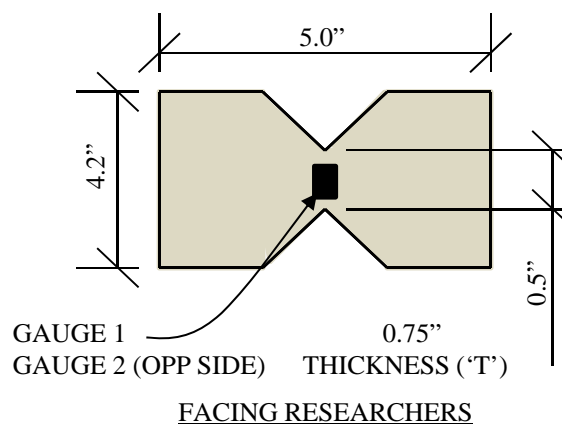
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-SXY-N40-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **17,810** **lbs**
 Shear Strength, S_{xy} : **30,763** **psi**
 Shear Modulus, G_{xy} : **1,364,919** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT1-SXY-01-N40-FY09 | 17,483 | 29,752 | 1,277,247 | Shear |
| 2 | MAT1-SXY-02-N40-FY09 | 17,984 | 31,448 | 1,417,720 | Shear |
| 3 | MAT1-SXY-03-N40-FY09 | 17,709 | 30,800 | 1,357,034 | Shear |
| 4 | MAT1-SXY-04-N40-FY09 | 17,825 | 30,796 | 1,428,681 | Shear |
| 5 | MAT1-SXY-05-N40-FY09 | 18,050 | 31,019 | 1,343,912 | Shear |
| Average | | 17,810 | 30,763 | 1,364,919 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets D-38 to D-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-01-N40-FY09
 Test Date: 3/16/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 17,483 lbs
 Shear Strength, S_{xy} : 29,752 psi
 Shear Modulus, G_{xy} : 1,277,247 psi

Measured Specimen Dimensions:

Thickness, T: 1.0550 in
 Notch Length, N: 0.5570 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,497 lbs
 50% Max Load: 8,742 lbs

PICTURE OF SPECIMEN PRE-TEST



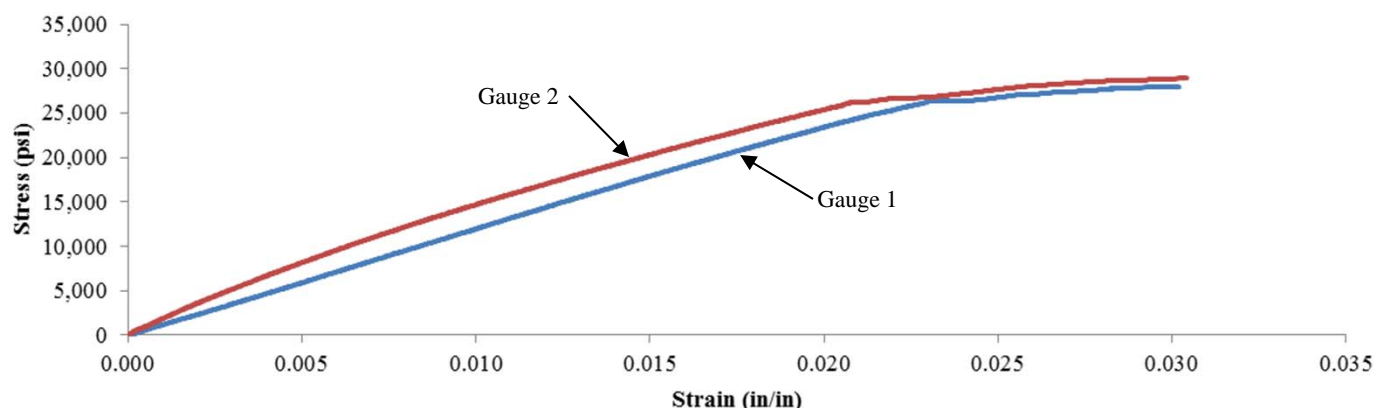
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01241 | 0.00503 | 1,210,456 |
| 2 | 0.01014 | 0.00350 | 1,344,037 |
| Average | | | 1,277,247 |

Stress-Strain Curve -40°F_1_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-02-N40-FY09
 Test Date: 3/20/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 17,984 lbs
 Shear Strength, S_{xy} : 31,448 psi
 Shear Modulus, G_{xy} : 1,417,720 psi

Measured Specimen Dimensions:

Thickness, T : 1.0590 in
 Notch Length, N : 0.5400 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,597 lbs
 50% Max Load: 8,992 lbs

PICTURE OF SPECIMEN PRE-TEST



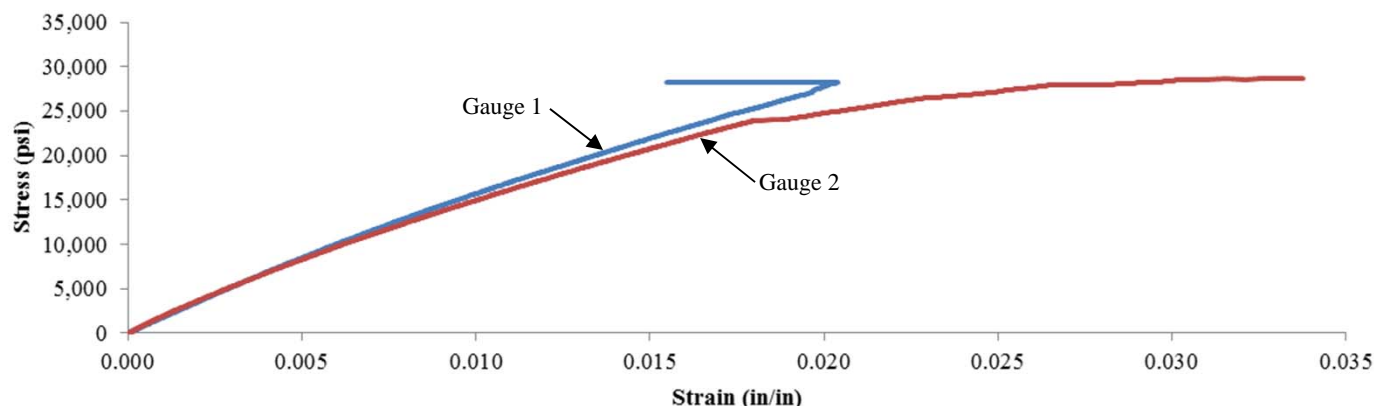
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00999 | 0.00362 | 1,479,255 |
| 2 | 0.01060 | 0.00365 | 1,356,184 |
| Average | | | 1,417,720 |

Stress-Strain Curve -40°F_2_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-03-N40-FY09
 Test Date: 03/20/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

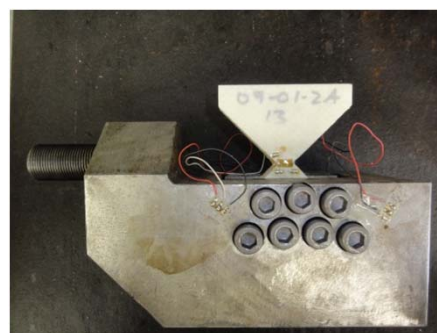
Average Material Properties:

Maximum Load, P_{max} : 17,709 lbs
 Shear Strength, S_{xy} : 30,800 psi
 Shear Modulus, G_{xy} : 1,357,034 psi

Measured Specimen Dimensions:

Thickness, T: 1.0550 in
 Notch Length, N: 0.5450 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,542 lbs
 50% Max Load: 8,855 lbs

PICTURE OF SPECIMEN PRE-TEST



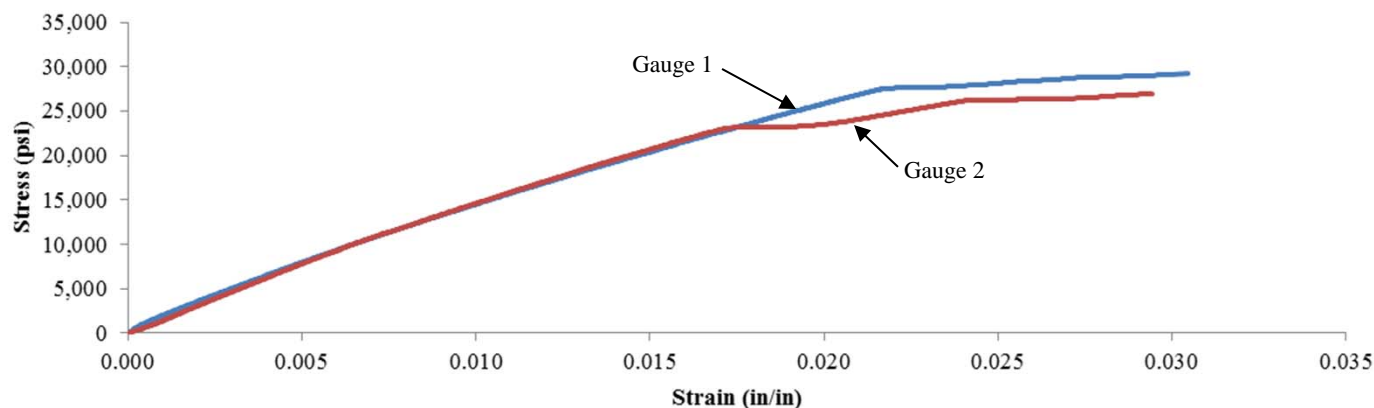
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01070 | 0.00374 | 1,328,209 |
| 2 | 0.01061 | 0.00394 | 1,385,859 |
| Average | | | 1,357,034 |

Stress-Strain Curve -40°F_3_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-04-N40-FY09
 Test Date: 3/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

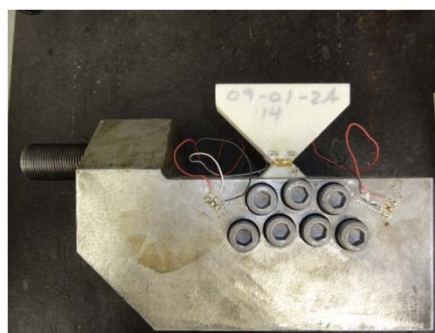
Average Material Properties:

Maximum Load, P_{max} : 17,825 lbs
 Shear Strength, S_{xy} : 30,796 psi
 Shear Modulus, G_{xy} : 1,428,681 psi

Measured Specimen Dimensions:

Thickness, T: 1.0620 in
 Notch Length, N: 0.5450 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,565 lbs
 50% Max Load: 8,912 lbs

PICTURE OF SPECIMEN PRE-TEST



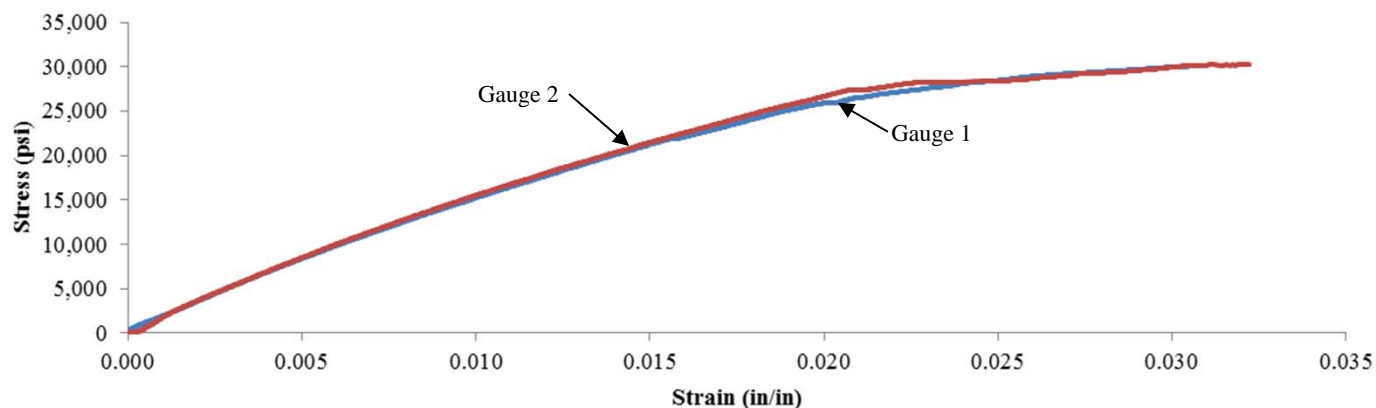
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01010 | 0.00354 | 1,407,927 |
| 2 | 0.00988 | 0.00351 | 1,449,434 |
| Average | | | 1,428,681 |

Stress-Strain Curve -40°F_4_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-05-N40-FY09
 Test Date: 3/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 18,050 lbs
 Shear Strength, S_{xy} : 31,019 psi
 Shear Modulus, G_{xy} : 1,343,912 psi

Measured Specimen Dimensions:

Thickness, T : 1.0580 in
 Notch Length, N : 0.5500 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,610 lbs
 50% Max Load: 9,025 lbs

PICTURE OF SPECIMEN PRE-TEST



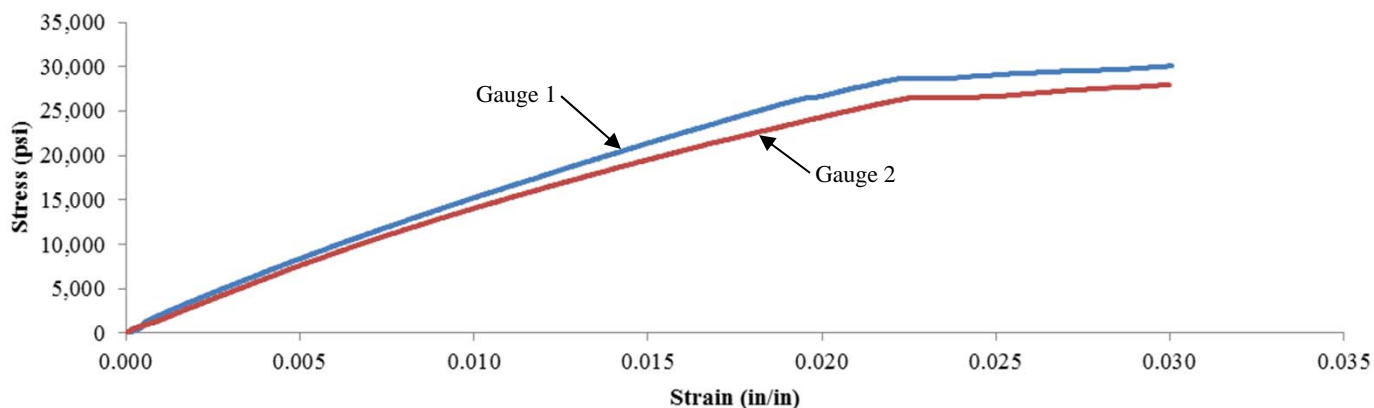
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01020 | 0.00355 | 1,398,892 |
| 2 | 0.01126 | 0.00404 | 1,288,932 |
| Average | | | 1,343,912 |

Stress-Strain Curve -40°F_5_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

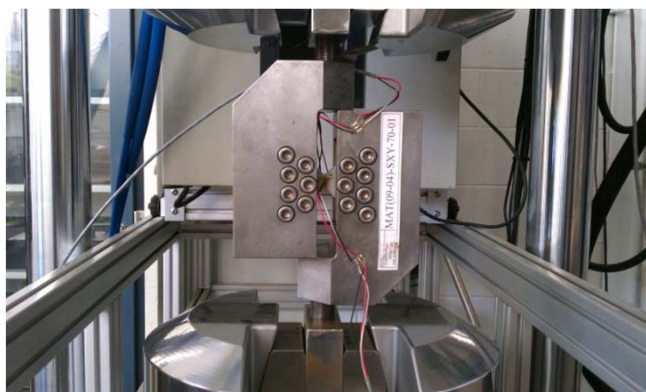
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-SXY-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **12,402** **lbs**
 Shear Strength, S_{xy} : **23,625** **psi**
 Shear Modulus, G_{xy} : **1,336,103** **psi**

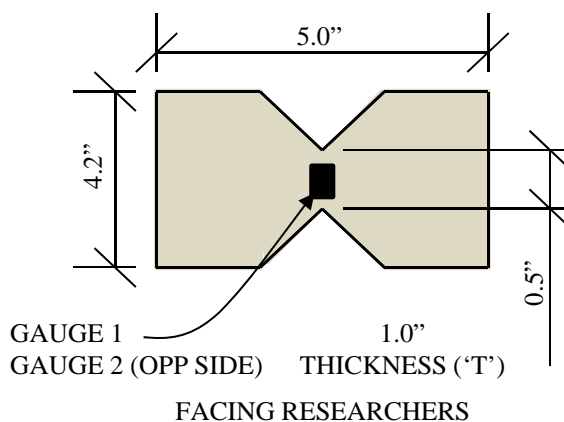
| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT1-SXY-01-70-FY09 | 11,909 | 23,350 | 1,275,765 | Shear |
| 2 | MAT1-SXY-02-70-FY09 | 11,975 | 23,434 | 1,385,690 | Shear |
| 3 | MAT1-SXY-03-70-FY09 | 11,845 | 22,780 | 1,422,244 | Shear |
| 4 | MAT1-SXY-04-70-FY09 | 12,470 | 24,119 | 1,282,020 | Shear |
| 5 | MAT1-SXY-05-70-FY09 | 13,809 | 24,441 | 1,314,797 | Shear |
| Average | | 12,402 | 23,625 | 1,336,103 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets D-44 to D-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-01-70-FY09
 Test Date: 02/07/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,909 lbs
 Shear Strength, S_{xy} : 23,350 psi
 Shear Modulus, G_{xy} : 1,275,765 psi

Measured Specimen Dimensions:

Thickness, T: 0.940 in
 Notch Length, N: 0.543 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,382 lbs
 50% Max Load: 5,954 lbs

PICTURE OF SPECIMEN PRE-TEST



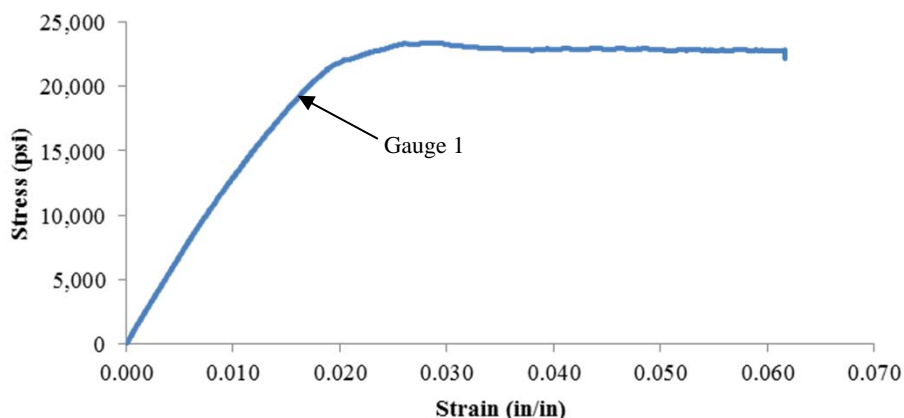
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00888 | 0.00339 | 1,275,765 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 1,275,765 |

Stress-Strain Curve 70F_01_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-02-70-FY09
 Test Date: 02/07/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,975 lbs
 Shear Strength, S_{xy} : 23,434 psi
 Shear Modulus, G_{xy} : 1,385,690 psi

Measured Specimen Dimensions:

Thickness, T: 0.943 in
 Notch Length, N: 0.540 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,395 lbs
 50% Max Load: 5,987 lbs

PICTURE OF SPECIMEN PRE-TEST



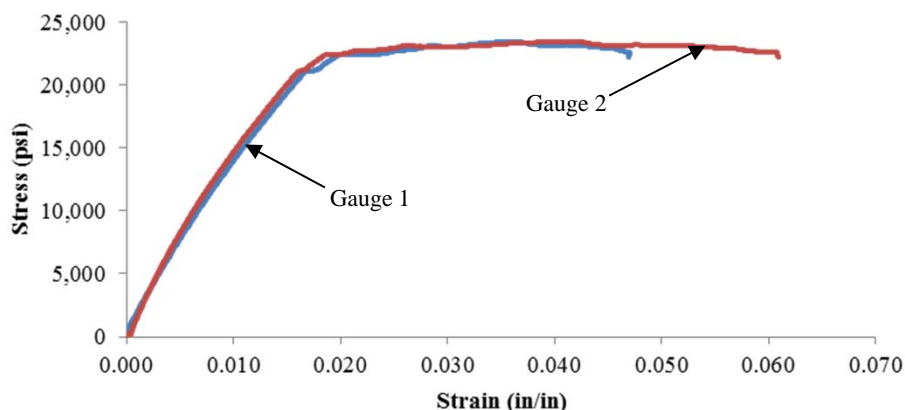
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00806 | 0.00277 | 1,328,049 |
| 2 | 0.00755 | 0.00268 | 1,443,331 |
| Average | | | 1,385,690 |

Stress-Strain Curve 70F_02_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-03-70-FY09
 Test Date: 02/07/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,845 lbs
 Shear Strength, S_{xy} : 22,780 psi
 Shear Modulus, G_{xy} : 1,422,244 psi

Measured Specimen Dimensions:

Thickness, T: 0.948 in
 Notch Length, N: 0.548 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,369 lbs
 50% Max Load: 5,923 lbs

PICTURE OF SPECIMEN PRE-TEST



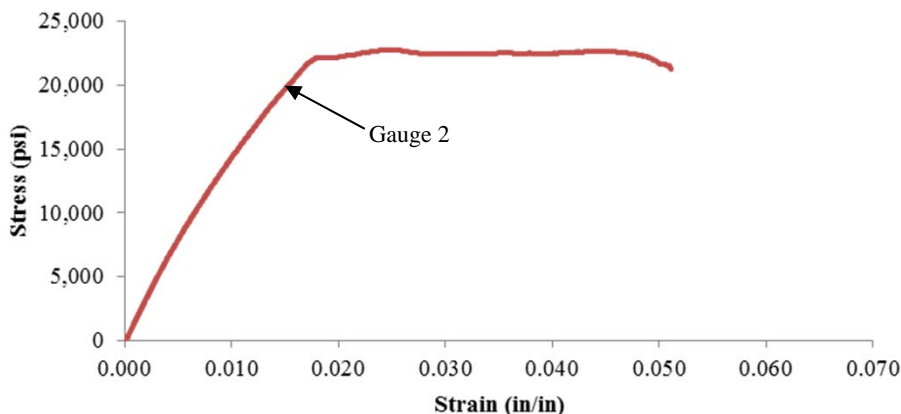
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | Lost Gauge | Lost Gauge | - |
| 2 | 0.00755 | 0.00275 | 1,422,244 |
| Average | | | 1,422,244 |

Stress-Strain Curve 70F_03_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-04-70-FY09
 Test Date: 02/09/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,470 lbs
 Shear Strength, S_{xy} : 24,119 psi
 Shear Modulus, G_{xy} : 1,282,020 psi

Measured Specimen Dimensions:

Thickness, T: 0.948 in
 Notch Length, N: 0.545 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,494 lbs
 50% Max Load: 6,235 lbs

PICTURE OF SPECIMEN PRE-TEST



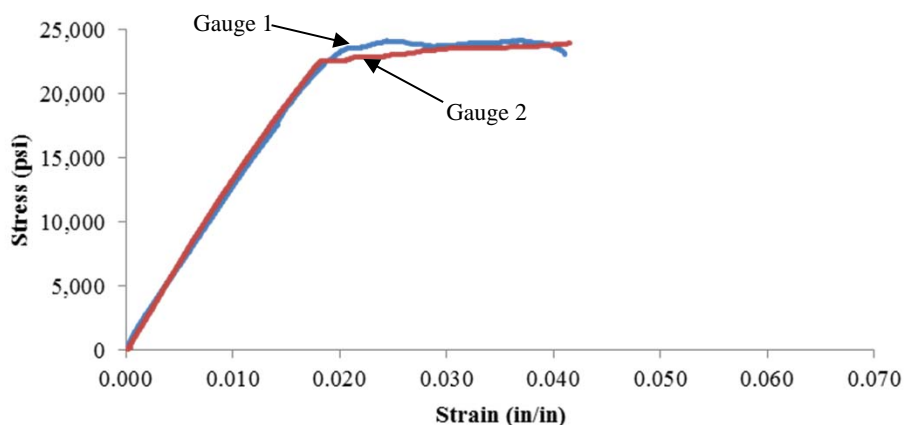
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00937 | 0.00349 | 1,229,819 |
| 2 | 0.00896 | 0.00354 | 1,334,222 |
| Average | | | 1,282,020 |

Stress-Strain Curve 70F_04_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-05-70-FY09
 Test Date: 02/09/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 13,809 lbs
 Shear Strength, S_{xy} : 24,441 psi
 Shear Modulus, G_{xy} : 1,314,797 psi

Measured Specimen Dimensions:

Thickness, T : 1.056 in
 Notch Length, N : 0.535 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,762 lbs
 50% Max Load: 6,905 lbs

PICTURE OF SPECIMEN PRE-TEST



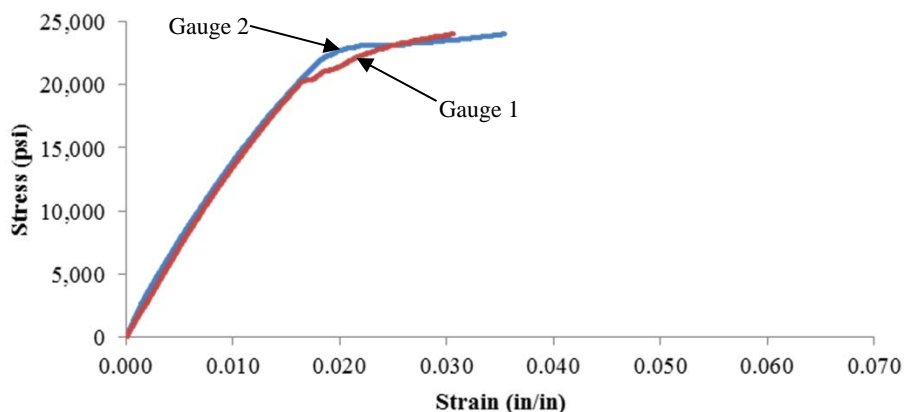
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00857 | 0.00293 | 1,301,064 |
| 2 | 0.00892 | 0.00341 | 1,328,529 |
| Average | | | 1,314,797 |

Stress-Strain Curve 70F_05_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

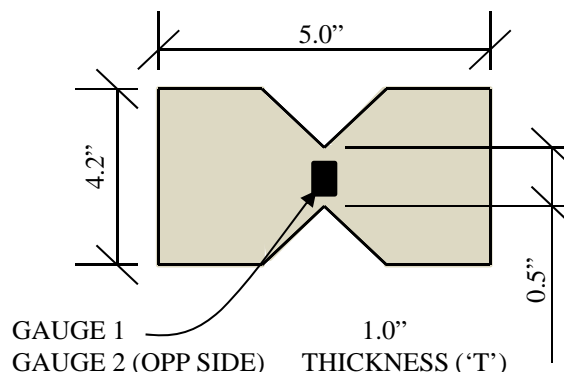
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-SXY-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **8,128** **lbs**
 Shear Strength, S_{xy} : **15,145** **psi**
 Shear Modulus, G_{xy} : **1,034,024** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT1-SXY-01-140-FY09 | 8,182 | 15,857 | 1,163,354 | Shear |
| 2 | MAT1-SXY-02-140-FY09 | 6,755 | 12,990 | 1,024,740 | Shear |
| 3 | MAT1-SXY-03-140-FY09 | 9,101 | 17,915 | 859,478 | Shear |
| 4 | MAT1-SXY-04-140-FY09 | 8,960 | 15,720 | 1,141,545 | Shear |
| 5 | MAT1-SXY-05-140-FY09 | 7,640 | 13,241 | 981,002 | Shear |
| Average | | 8,128 | 15,145 | 1,034,024 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets D-50 to D-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-01-140-FY09
 Test Date: 02/10/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 8,182 lbs
 Shear Strength, S_{xy} : 15,857 psi
 Shear Modulus, G_{xy} : 1,163,354 psi

Measured Specimen Dimensions:

Thickness, T: 0.938 in
 Notch Length, N: 0.550 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,636 lbs
 50% Max Load: 4,091 lbs

PICTURE OF SPECIMEN PRE-TEST



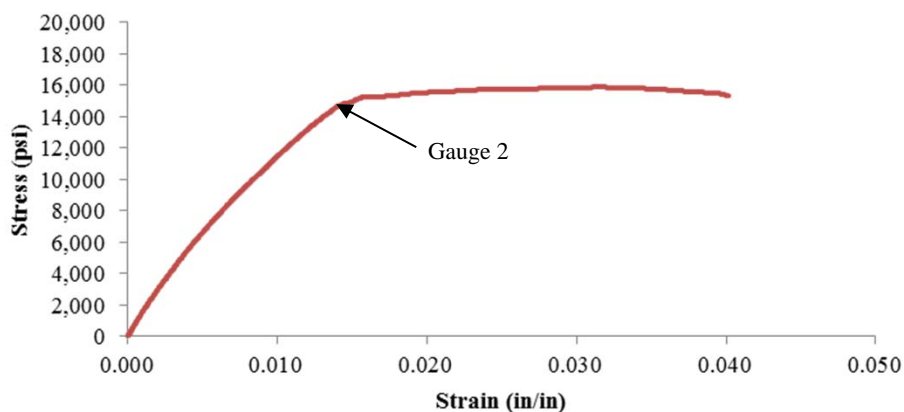
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | Lost Gauge | Lost Gauge | - |
| 2 | 0.00626 | 0.00217 | 1,163,354 |
| Average | | | 1,163,354 |

Stress-Strain Curve 140F_01_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-02-140-FY09
 Test Date: 02/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 6,755 lbs
 Shear Strength, S_{xy} : 12,990 psi
 Shear Modulus, G_{xy} : 1,024,740 psi

Measured Specimen Dimensions:

Thickness, T: 0.945 in
 Notch Length, N: 0.550 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,351 lbs
 50% Max Load: 3,377 lbs

PICTURE OF SPECIMEN PRE-TEST



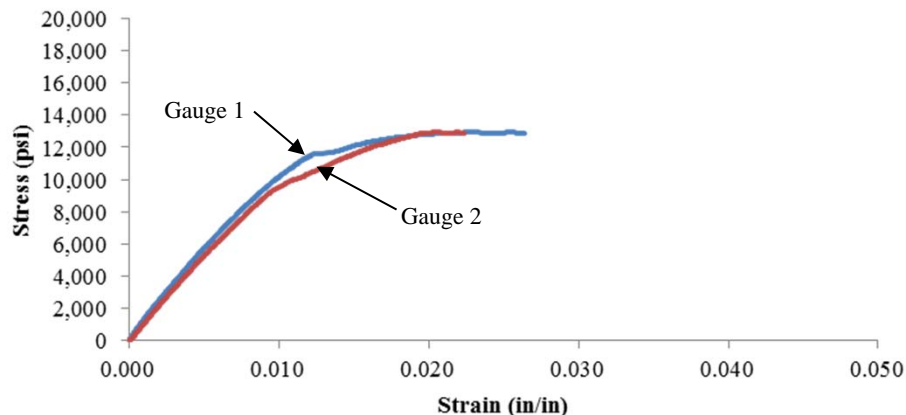
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00576 | 0.00206 | 1,055,348 |
| 2 | 0.00629 | 0.00237 | 994,132 |
| Average | | | 1,024,740 |

Stress-Strain Curve 140F_02_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-03-140-FY09
 Test Date: 02/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,101 lbs
 Shear Strength, S_{xy} : 17,915 psi
 Shear Modulus, G_{xy} : 859,478 psi

Measured Specimen Dimensions:

Thickness, T: 0.941 in
 Notch Length, N: 0.540 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,820 lbs
 50% Max Load: 4,550 lbs

PICTURE OF SPECIMEN PRE-TEST



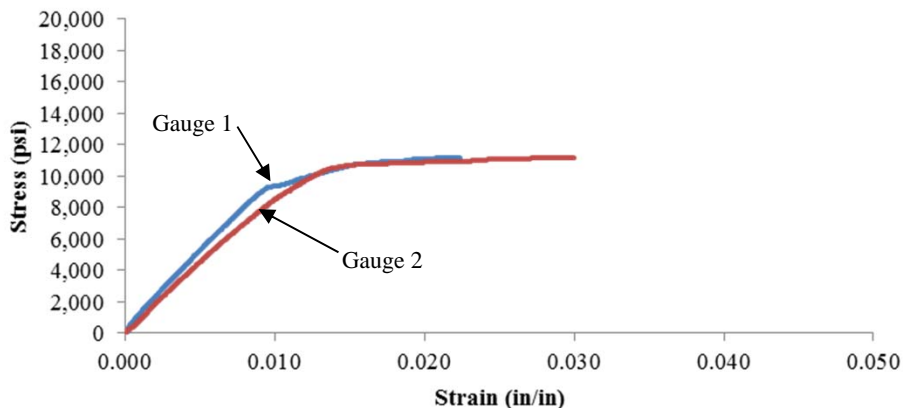
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00904 | 0.00327 | 931,294 |
| 2 | 0.01074 | 0.00391 | 787,662 |
| Average | | | 859,478 |

Stress-Strain Curve 140F_03_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-04-140-FY09
 Test Date: 02/22/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 8,960 lbs
 Shear Strength, S_{xy} : 15,720 psi
 Shear Modulus, G_{xy} : 1,141,545 psi

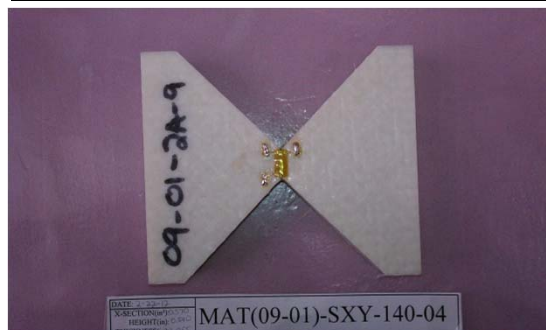
Measured Specimen Dimensions:

Thickness, T: 1.055 in
 Notch Length, N: 0.540 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,782 lbs
 50% Max Load: 4,480 lbs

PICTURE OF SPECIMEN PRE-TEST



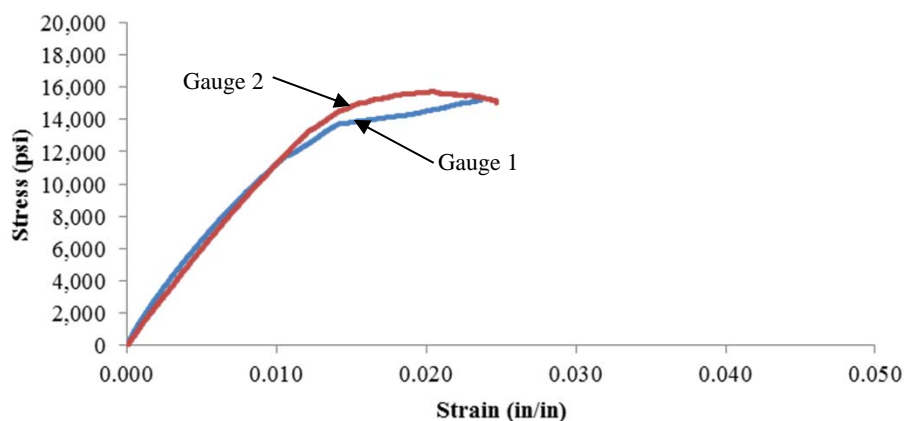
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00627 | 0.00212 | 1,136,093 |
| 2 | 0.00668 | 0.00257 | 1,146,997 |
| Average | | | 1,141,545 |

Stress-Strain Curve 140F_04_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT1-SXY-05-140-FY09
 Test Date: 02/22/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,640 lbs
 Shear Strength, S_{xy} : 13,241 psi
 Shear Modulus, G_{xy} : 981,002 psi

Measured Specimen Dimensions:

Thickness, T: 1.044 in
 Notch Length, N: 0.553 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,528 lbs
 50% Max Load: 3,820 lbs

PICTURE OF SPECIMEN PRE-TEST



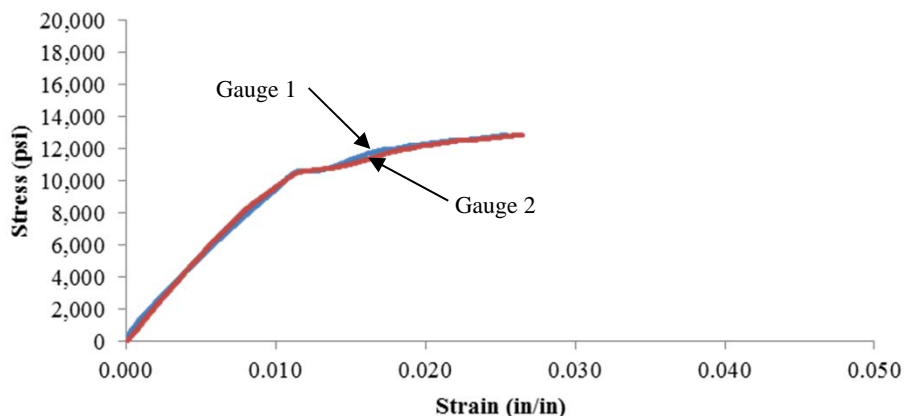
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00649 | 0.00218 | 922,709 |
| 2 | 0.00621 | 0.00239 | 1,039,295 |
| Average | | | 981,002 |

Stress-Strain Curve 140F_05_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

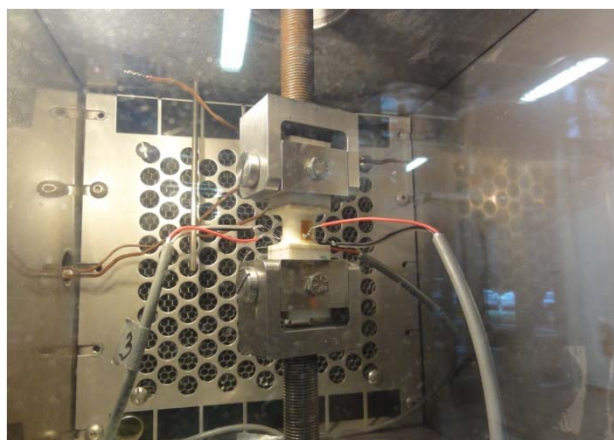
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TZ-N40-FY09
Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
Nominal Temperature: -40°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 1,855 lbs
 Tensile Strength, ST_z : 4,604 psi
 Tensile Modulus, E_z : 1,140,678 psi

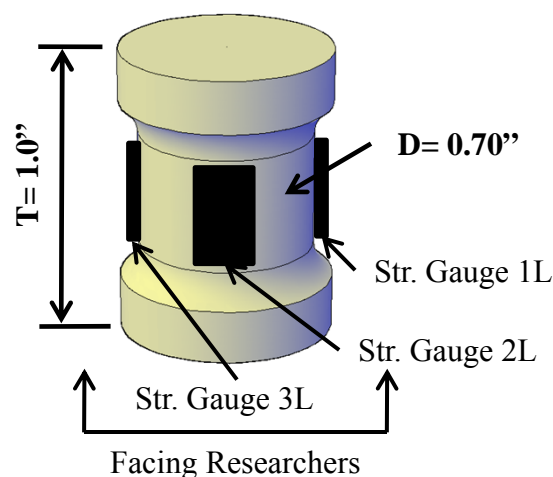
| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT1-TZ-1-N40-FY09 | 1,954 | 4,800 | 1,192,990 | Rupture |
| MAT1-TZ-2-N40-FY09 | 1,963 | 4,834 | 1,179,204 | Rupture |
| MAT1-TZ-3-N40-FY09 | 1,970 | 4,837 | 1,114,139 | Rupture |
| MAT1-TZ-4-N40-FY09 | 1,911 | 4,680 | 1,016,217 | Rupture |
| MAT1-TZ-5-N40-FY09 | 1,475 | 3,867 | 1,200,840 | Rupture |
| Average | 1,855 | 4,604 | 1,140,678 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Notes:**

- 1) Reference D-56 to D-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-N40-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

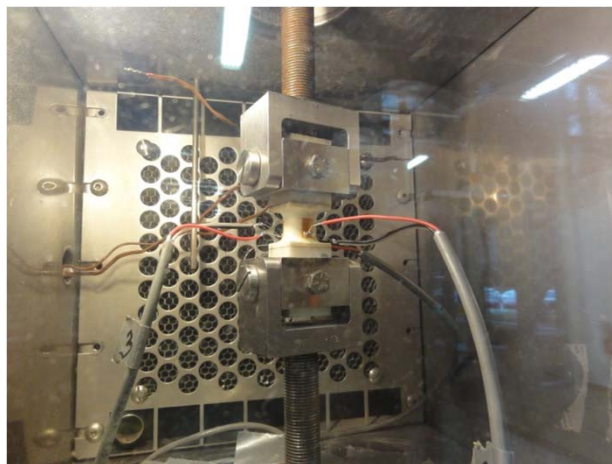
Average Material Properties:

Tensile Strength, ST_z : 4,800 psi
 Tensile Modulus, E_z : 1,192,990 psi

Measured Specimen Dimensions:

Diameter, D: 0.720 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,400 psi
 20% Max Stress: 960 psi

PICTURE OF SPECIMEN PRE-TEST



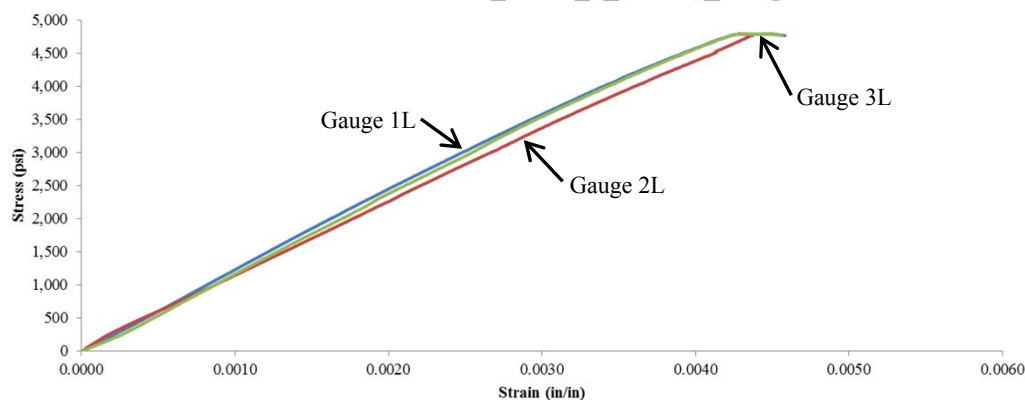
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001956 | 0.000786 | 1,231,309 |
| 2L | 0.002116 | 0.000836 | 1,124,762 |
| 3L | 0.002015 | 0.000838 | 1,222,901 |
| Average | | | 1,192,990 |

Stress-Strain Curve_-40°F_1_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-N40-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

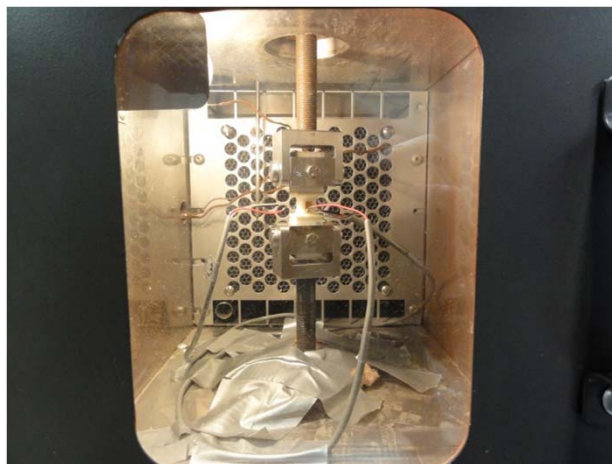
Average Material Properties:

Tensile Strength, ST_z : 4,834 psi
 Tensile Modulus, E_z : 1,179,204 psi

Measured Specimen Dimensions:

Diameter, D: 0.719 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,417 psi
 20% Max Stress: 967 psi

PICTURE OF SPECIMEN PRE-TEST

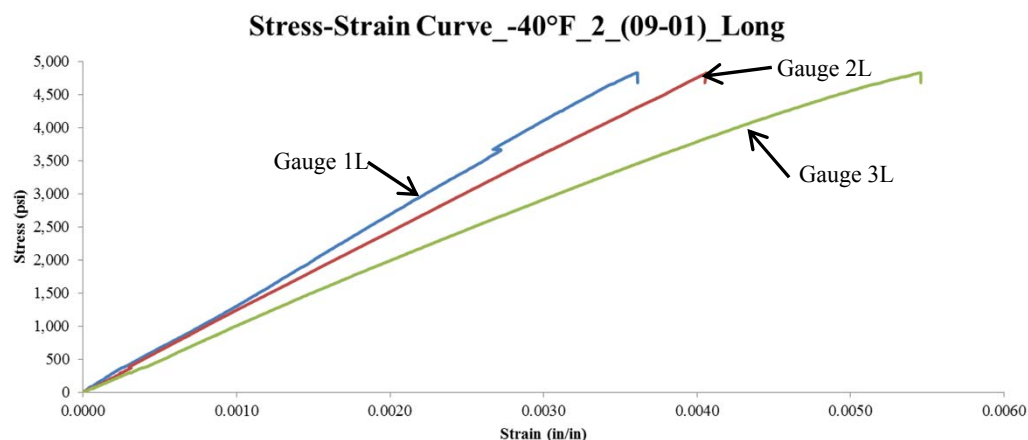


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001796 | 0.000739 | 1,371,233 |
| 2L | 0.001988 | 0.000770 | 1,190,900 |
| 3L | 0.002447 | 0.000960 | 975,479 |
| Average | | | 1,179,204 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-N40-FY09**
 Test Date: 11/30/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

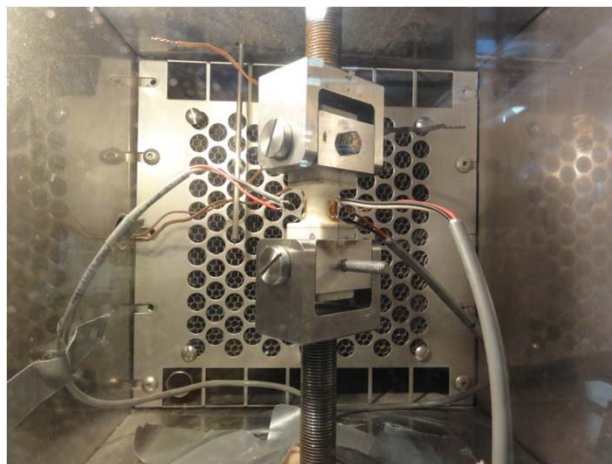
Average Material Properties:

Tensile Strength, ST_z : 4,837 psi
 Tensile Modulus, E_z : 1,114,139 psi

Measured Specimen Dimensions:

Diameter, D: 0.720 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,419 psi
 20% Max Stress: 967 psi

PICTURE OF SPECIMEN PRE-TEST



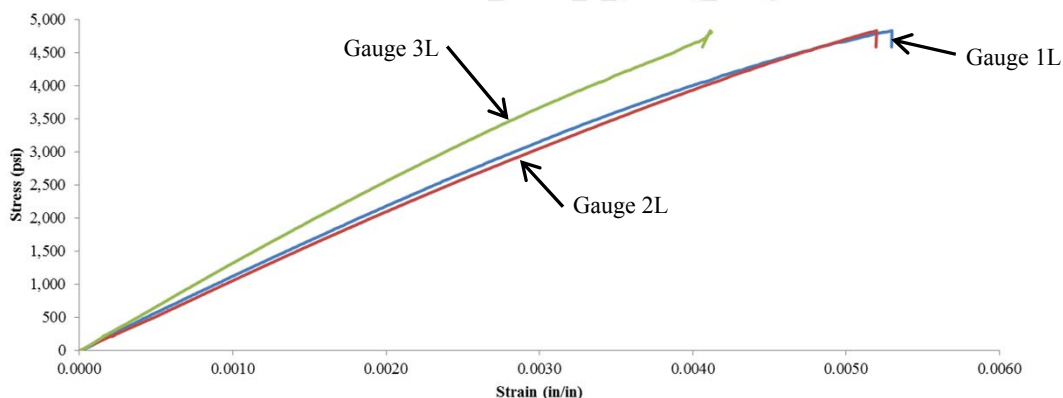
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002234 | 0.000859 | 1,055,178 |
| 2L | 0.002325 | 0.000917 | 1,030,414 |
| 3L | 0.001885 | 0.000731 | 1,256,826 |
| Average | | | 1,114,139 |

Stress-Strain Curve_-40°F_3_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-N40-FY09**
 Test Date: 11/30/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

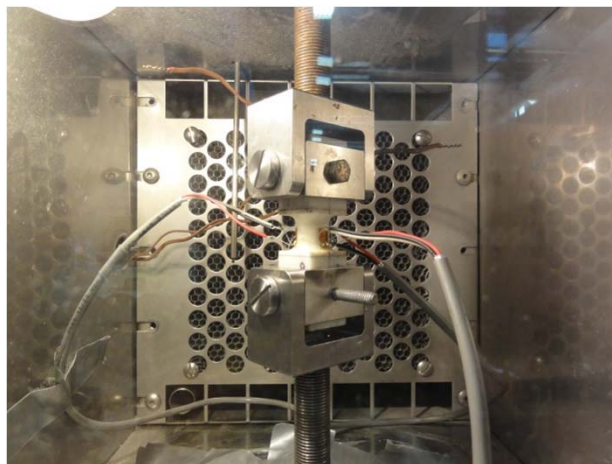
Average Material Properties:

Tensile Strength, ST_z : 4,680 psi
 Tensile Modulus, E_z : 1,016,217 psi

Measured Specimen Dimensions:

Diameter, D: 0.721 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,340 psi
 20% Max Stress: 936 psi

PICTURE OF SPECIMEN PRE-TEST

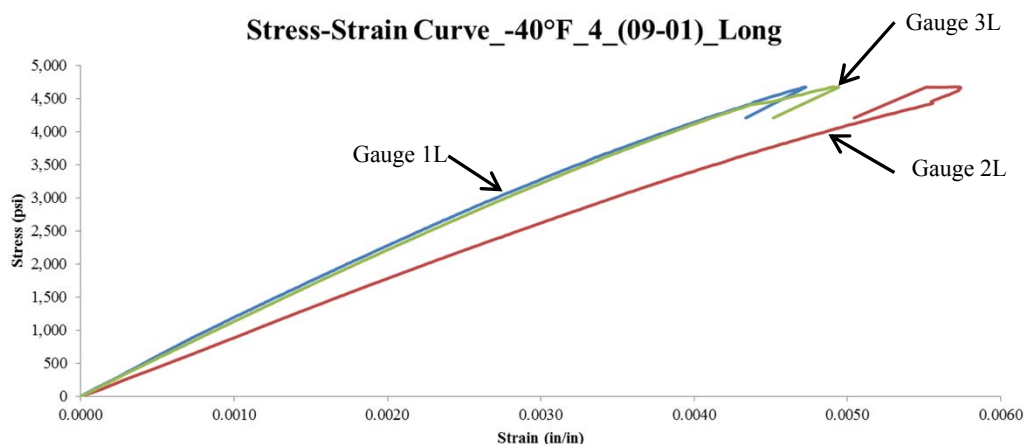


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002057 | 0.000770 | 1,091,097 |
| 2L | 0.002653 | 0.001051 | 876,589 |
| 3L | 0.002119 | 0.000820 | 1,080,966 |
| Average | | | 1,016,217 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-N40-FY09**
 Test Date: 11/30/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

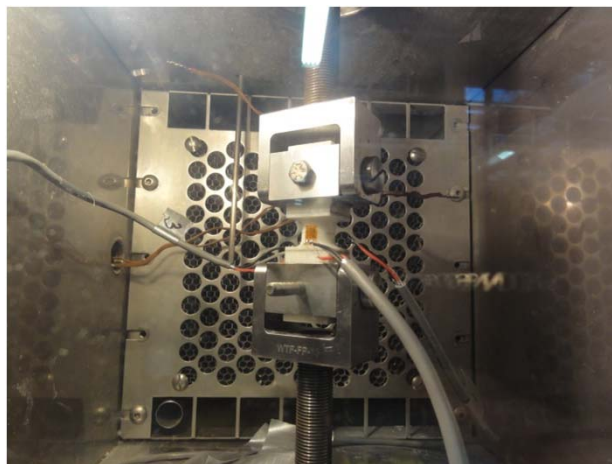
Average Material Properties:

Tensile Strength, ST_z : 3,867 psi
 Tensile Modulus, E_z : 1,200,840 psi

Measured Specimen Dimensions:

Diameter, D: 0.697 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,933 psi
 20% Max Stress: 773 psi

PICTURE OF SPECIMEN PRE-TEST



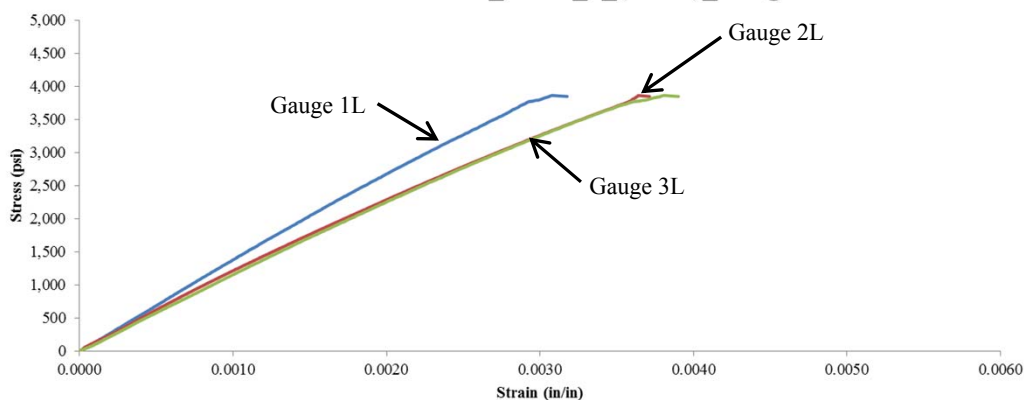
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001413 | 0.000558 | 1,356,879 |
| 2L | 0.001655 | 0.000620 | 1,119,908 |
| 3L | 0.001697 | 0.000667 | 1,125,733 |
| Average | | | 1,200,840 |

Stress-Strain Curve_-40°F_5_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-TZ-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 70°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 1,260 lbs

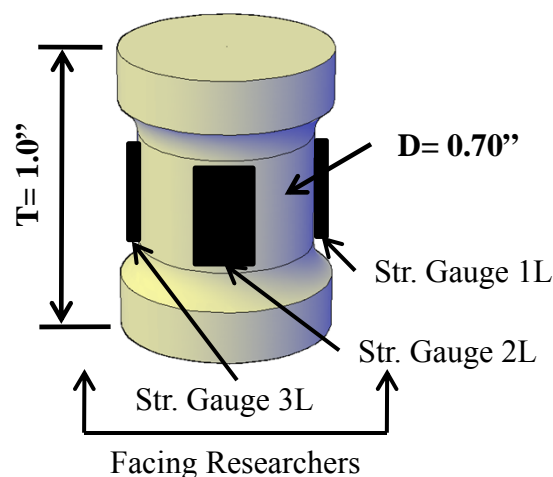
Tensile Strength, ST_z : 3,095 psi

Tensile Modulus, E_z : 931,037 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT1-TZ-1-70-FY09 | 1,273 | 3,127 | 924,327 | Rupture |
| MAT1-TZ-2-70-FY09 | 1,286 | 3,158 | 930,993 | Rupture |
| MAT1-TZ-3-70-FY09 | 1,396 | 3,438 | 961,490 | Rupture |
| MAT1-TZ-4-70-FY09 | 1,114 | 2,736 | 920,227 | Rupture |
| MAT1-TZ-5-70-FY09 | 1,233 | 3,019 | 918,149 | Rupture |
| Average | 1,260 | 3,095 | 931,037 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference D-62 to D-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-70-FY09**
 Test Date: 9/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

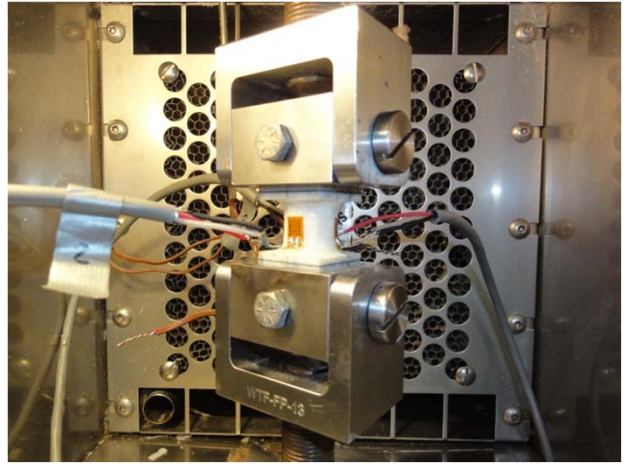
Average Material Properties:

Tensile Strength, ST_z : 3,127 psi
 Tensile Modulus, E_z : 924,327 psi

Measured Specimen Dimensions:

Diameter, D: 0.720 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,563 psi
 20% Max Stress: 625 psi

PICTURE OF SPECIMEN PRE-TEST



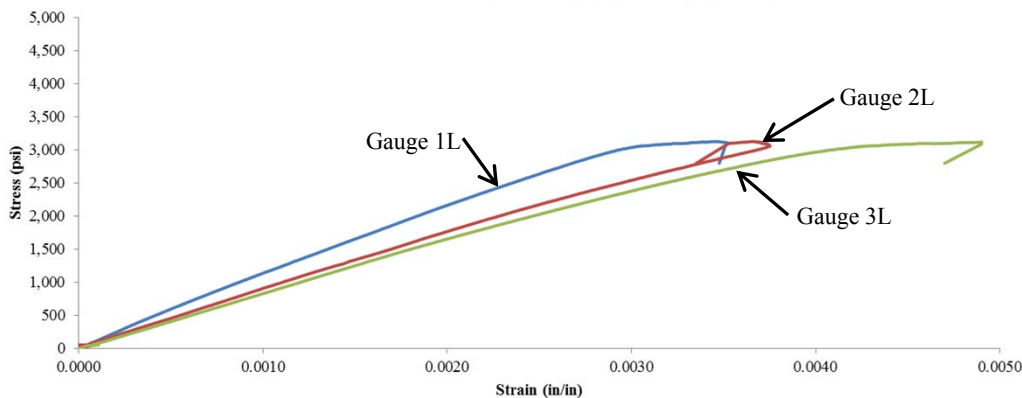
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001409 | 0.000526 | 1,062,445 |
| 2L | 0.001762 | 0.000687 | 872,242 |
| 3L | 0.001878 | 0.000759 | 838,293 |
| Average | | | 924,327 |

Stress-Strain Curve_70°F_1_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-70-FY09**
 Test Date: 9/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,158 psi
 Tensile Modulus, E_z : 930,993 psi

Measured Specimen Dimensions:

Diameter, D: 0.720 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,579 psi
 20% Max Stress: 632 psi

PICTURE OF SPECIMEN PRE-TEST



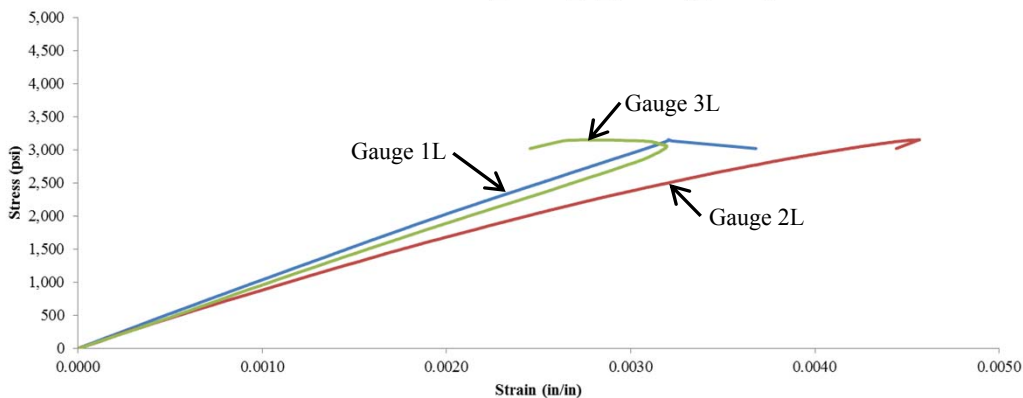
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001535 | 0.000603 | 1,017,097 |
| 2L | 0.001856 | 0.000701 | 820,207 |
| 3L | 0.001654 | 0.000663 | 955,677 |
| Average | | | 930,993 |

Stress-Strain Curve_70°F_2_(09-03)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-70-FY09**
 Test Date: 9/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

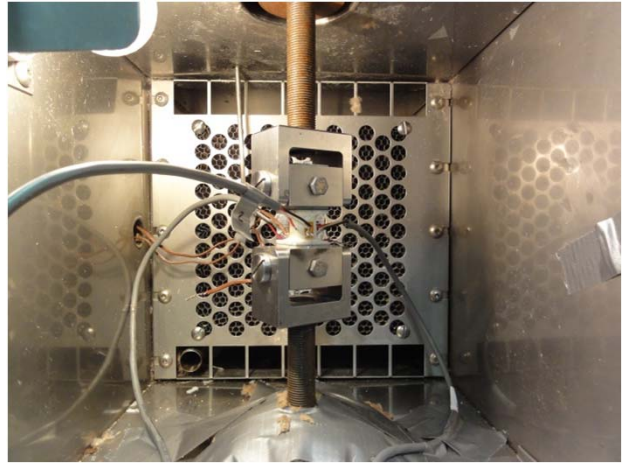
Average Material Properties:

Tensile Strength, ST_z : 3,438 psi
 Tensile Modulus, E_z : 961,490 psi

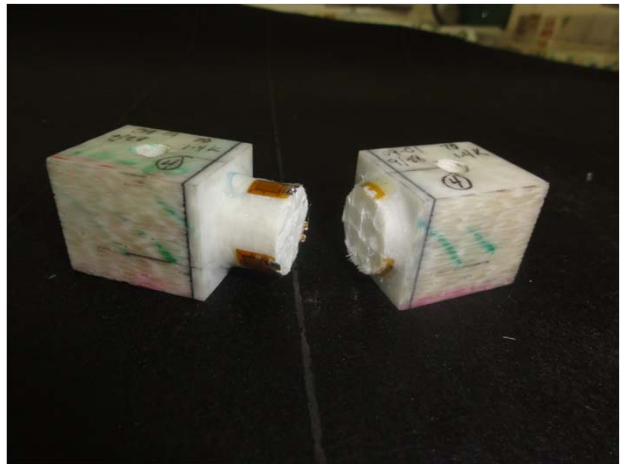
Measured Specimen Dimensions:

Diameter, D: 0.719 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,719 psi
 20% Max Stress: 688 psi

PICTURE OF SPECIMEN PRE-TEST



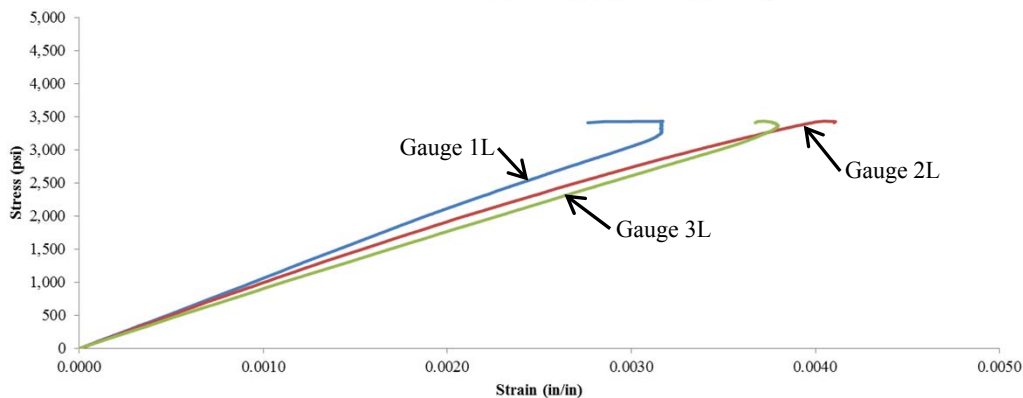
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001611 | 0.000649 | 1,071,442 |
| 2L | 0.001775 | 0.000677 | 939,746 |
| 3L | 0.001938 | 0.000757 | 873,282 |
| Average | | | 961,490 |

Stress-Strain Curve_70°F_3_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-70-FY09**
 Test Date: 9/28/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,736 psi
 Tensile Modulus, E_z : 920,227 psi

Measured Specimen Dimensions:

Diameter, D: 0.720 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,368 psi
 20% Max Stress: 547 psi

PICTURE OF SPECIMEN PRE-TEST



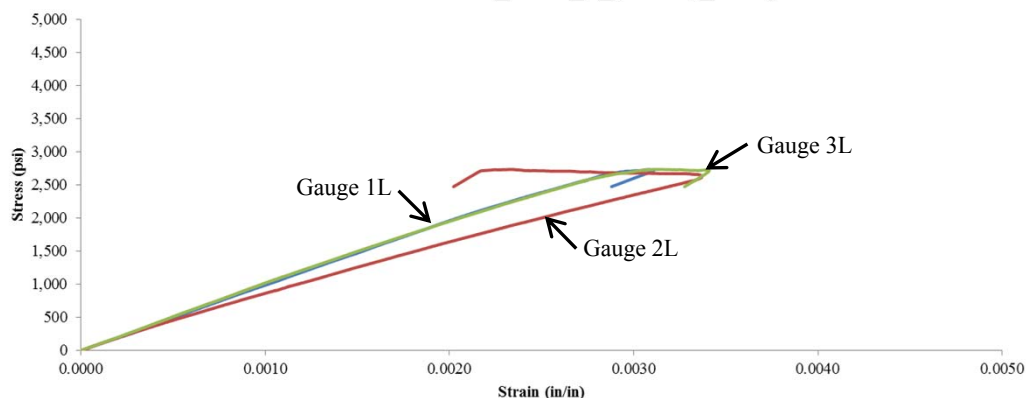
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001391 | 0.000557 | 984,427 |
| 2L | 0.001646 | 0.000609 | 791,826 |
| 3L | 0.001366 | 0.000532 | 984,427 |
| Average | | | 920,227 |

Stress-Strain Curve_70°F_4_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-70-FY09**
 Test Date: 9/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

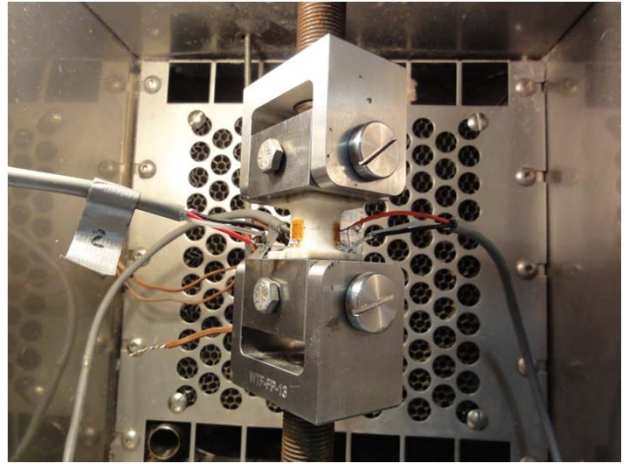
Average Material Properties:

Tensile Strength, ST_z : 3,019 psi
 Tensile Modulus, E_z : 918,149 psi

Measured Specimen Dimensions:

Diameter, D: 0.721 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,509 psi
 20% Max Stress: 604 psi

PICTURE OF SPECIMEN PRE-TEST



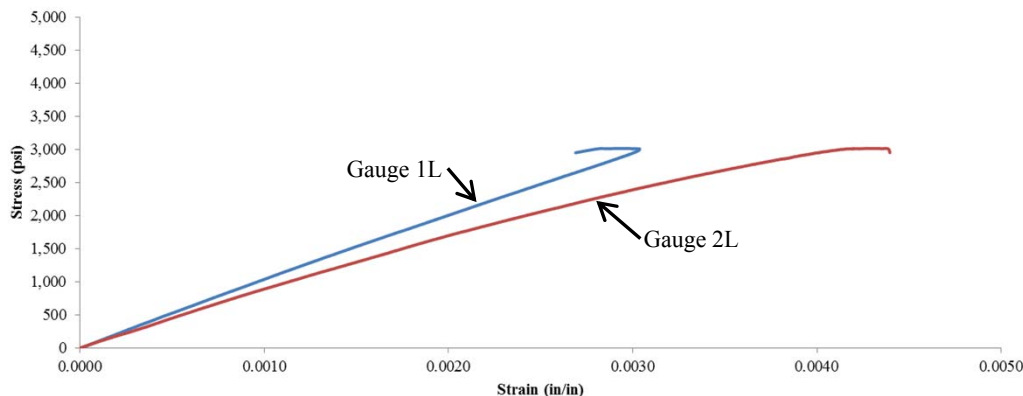
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001472 | 0.000573 | 1,006,710 |
| 2L | 0.001758 | 0.000666 | 829,588 |
| 3L | Lost | Gauge | Lost Gauge |
| Average | | | 918,149 |

Stress-Strain Curve_70°F_5_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

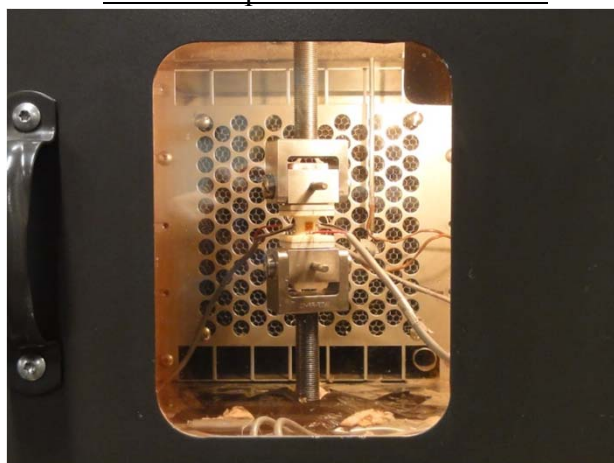
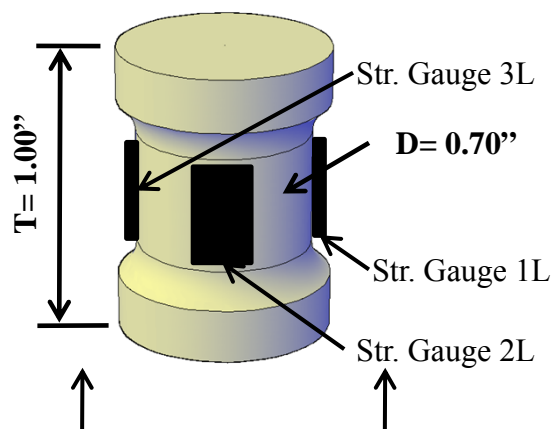
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-TZ-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **ST_z , E_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **708** lbs
 Tensile Strength, ST_z : **1,893** psi
 Tensile Modulus, E_z : **334,720** psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT1-TZ-1-140-FY09 | 677 | 1,790 | 342,881 | Rupture |
| MAT1-TZ-2-140-FY09 | 762 | 2,026 | 373,489 | Rupture |
| MAT1-TZ-3-140-FY09 | 666 | 1,786 | 353,077 | Rupture |
| MAT1-TZ-4-140-FY09 | 677 | 1,826 | 297,393 | Rupture |
| MAT1-TZ-5-140-FY09 | 757 | 2,035 | 306,759 | Rupture |
| Average | 708 | 1,893 | 334,720 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

Facing Researchers

Notes:

- 1.) Reference D-68 to D-72 for individual specimen test summary sheets and notes.
- 2.) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-1-140-FY09**
 Test Date: 5/16/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z , E_z

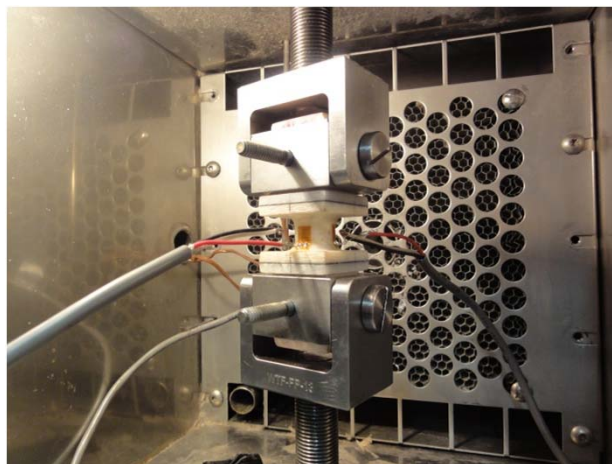
Average Material Properties:

Tensile Strength, ST_z : 1,790 psi
 Tensile Modulus, E_z : 342,881 psi

Measured Specimen Dimensions:

Diameter, D: 0.694 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 895 psi
 20% Max Stress: 358 psi

PICTURE OF SPECIMEN PRE-TEST



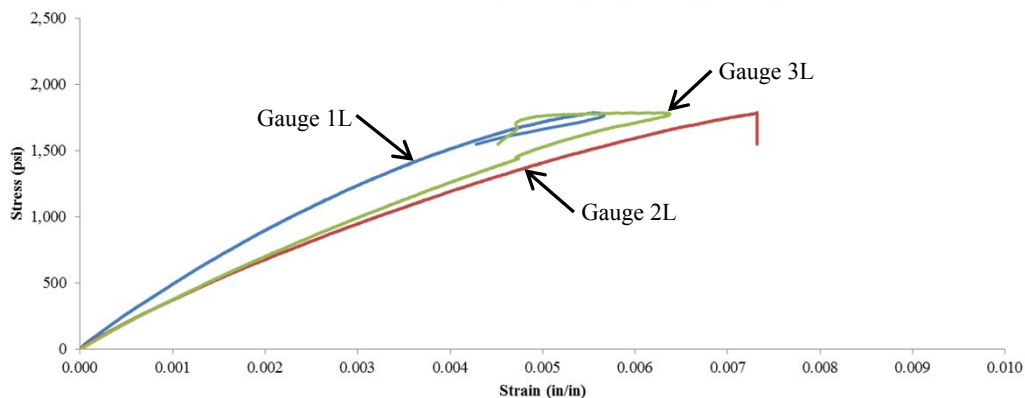
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001988 | 0.000706 | 418,735 |
| 2L | 0.002793 | 0.000962 | 293,308 |
| 3L | 0.002649 | 0.000953 | 316,602 |
| Average | | | 342,881 |

Stress-Strain Curve_140°F_1_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-2-140-FY09**
 Test Date: 5/16/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 2,026 psi
 Tensile Modulus, E_z : 373,489 psi

Measured Specimen Dimensions:

Diameter, D: 0.692 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,013 psi
 20% Max Stress: 405 psi

PICTURE OF SPECIMEN PRE-TEST



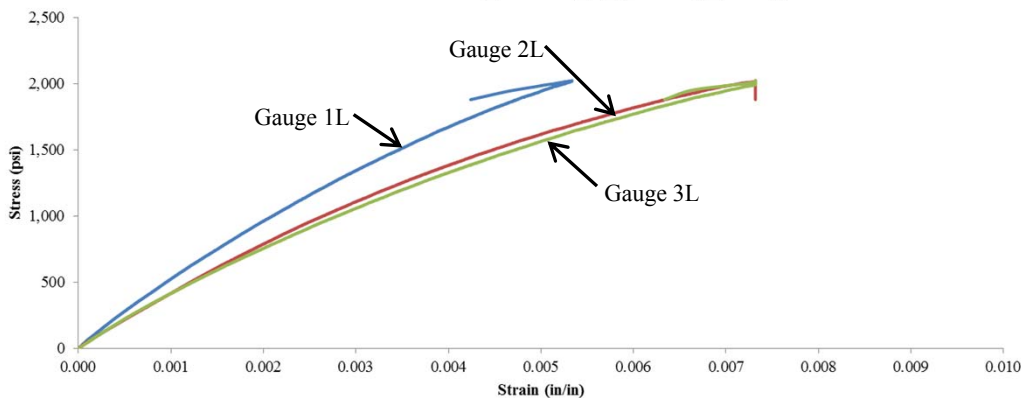
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002130 | 0.000753 | 441,449 |
| 2L | 0.002687 | 0.000972 | 354,470 |
| 3L | 0.002844 | 0.000971 | 324,547 |
| Average | | | 373,489 |

Stress-Strain Curve_140°F_2_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-3-140-FY09**
 Test Date: 5/17/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z , E_z

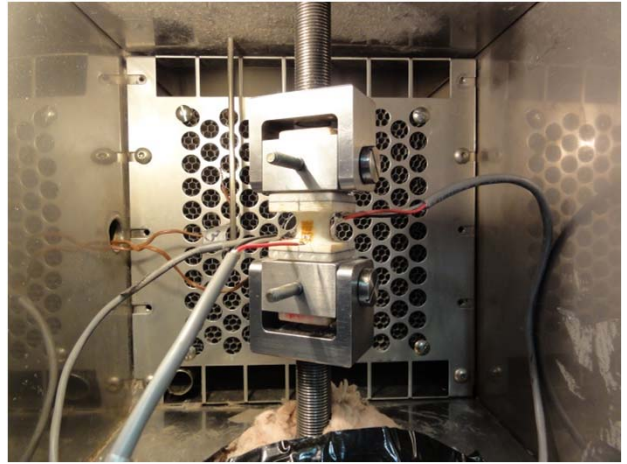
Average Material Properties:

Tensile Strength, ST_z : 1,786 psi
 Tensile Modulus, E_z : 353,077 psi

Measured Specimen Dimensions:

Diameter, D: 0.689 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 893 psi
 20% Max Stress: 357 psi

PICTURE OF SPECIMEN PRE-TEST



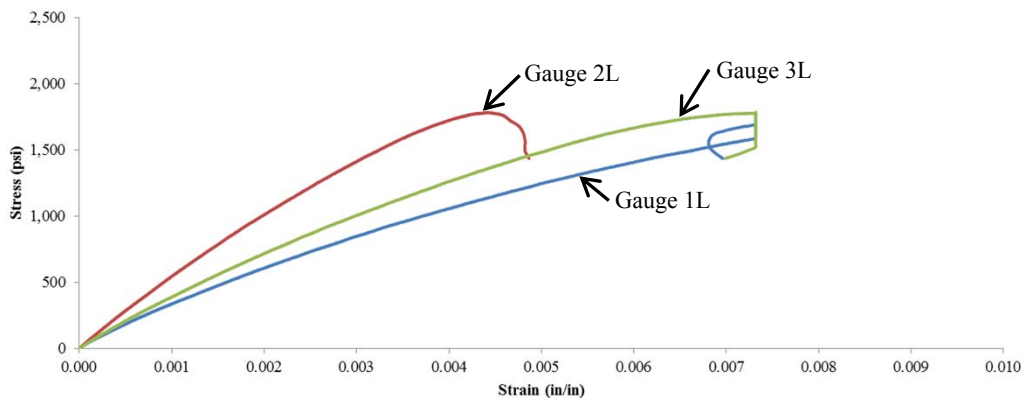
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.003202 | 0.001067 | 250,993 |
| 2L | 0.001728 | 0.000635 | 490,440 |
| 3L | 0.002589 | 0.000903 | 317,798 |
| Average | | | 353,077 |

Stress-Strain Curve_140°F_3_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-4-140-FY09**
 Test Date: 5/17/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z , E_z

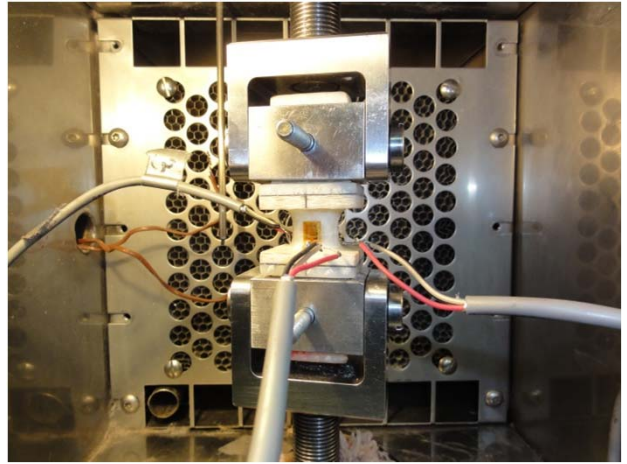
Average Material Properties:

Tensile Strength, ST_z : 1,826 psi
 Tensile Modulus, E_z : 297,393 psi

Measured Specimen Dimensions:

Diameter, D: 0.687 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 913 psi
 20% Max Stress: 365 psi

PICTURE OF SPECIMEN PRE-TEST



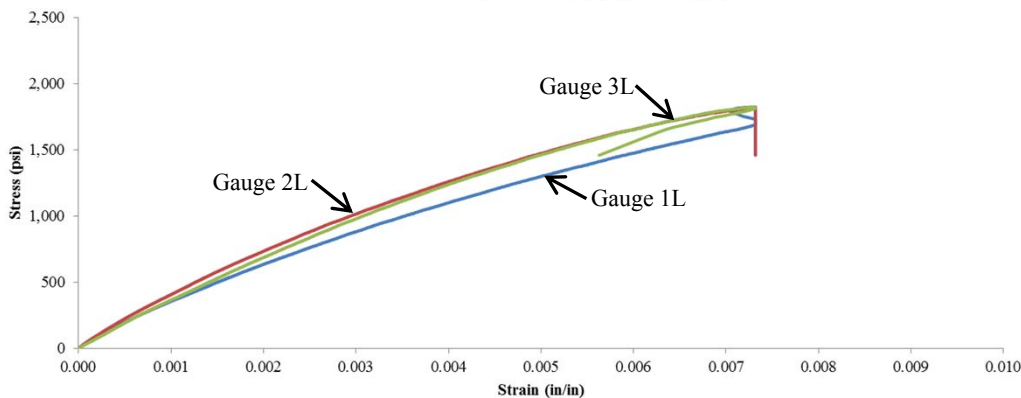
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.003126 | 0.001035 | 262,065 |
| 2L | 0.002607 | 0.000882 | 317,566 |
| 3L | 0.002754 | 0.001001 | 312,549 |
| Average | | | 297,393 |

Stress-Strain Curve_140°F_4_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-TZ-5-140-FY09**
 Test Date: 5/17/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z , E_z

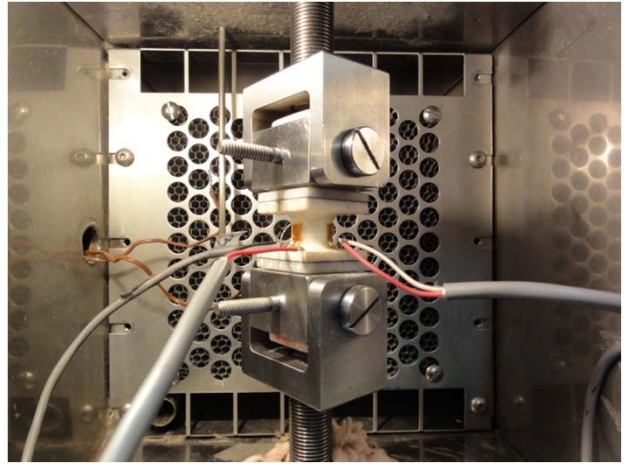
Average Material Properties:

Tensile Strength, ST_z : 2,035 psi
 Tensile Modulus, E_z : 306,759 psi

Measured Specimen Dimensions:

Diameter, D: 0.688 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,018 psi
 20% Max Stress: 407 psi

PICTURE OF SPECIMEN PRE-TEST



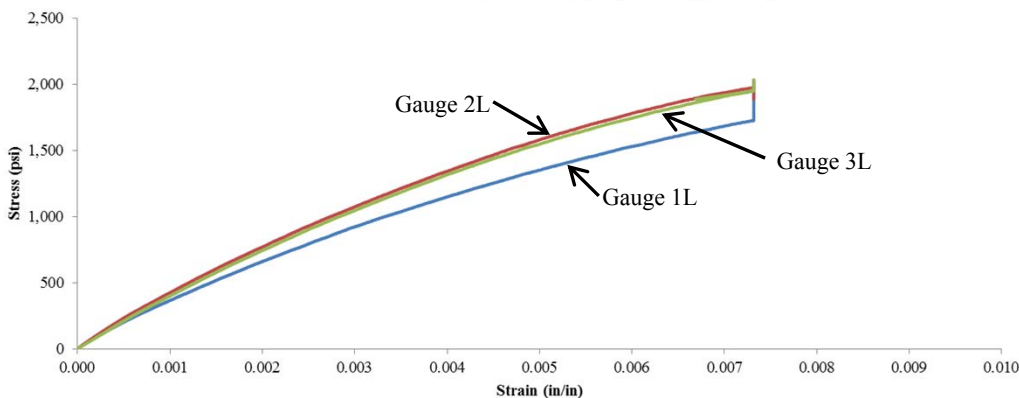
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.003410 | 0.001126 | 267,339 |
| 2L | 0.002803 | 0.000946 | 328,867 |
| 3L | 0.002898 | 0.001014 | 324,072 |
| Average | | | 306,759 |

Stress-Strain Curve_140°F_5_(09-01)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CZ-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 40,050 lbs

Compressive Strength, SC_z : 71,548 psi

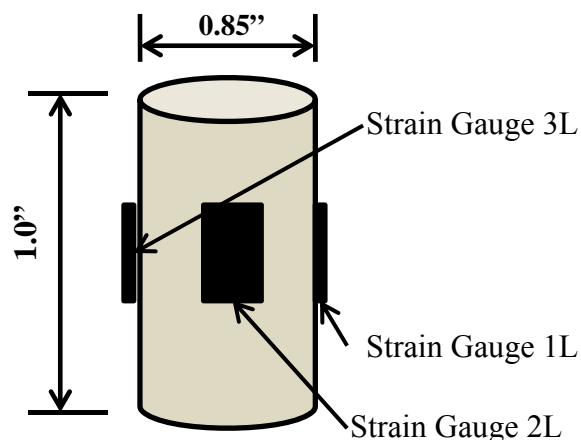
Compressive Modulus, E_z : 1,231,113 psi

Ultimate Strain, ϵ_z : 0.054 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT1-CZ-01-N40-FY09 | 42,712 | 76,163 | 1,181,014 | 0.0430 | Rupture |
| MAT1-CZ-02-N40-FY09 | 38,333 | 68,518 | 1,274,654 | 0.0543 | Rupture |
| MAT1-CZ-03-N40-FY09 | 39,582 | 70,582 | 1,172,459 | 0.0604 | Rupture |
| MAT1-CZ-04-N40-FY09 | 40,836 | 72,991 | 1,334,594 | 0.0548 | Rupture |
| MAT1-CZ-05-N40-FY09 | 38,784 | 69,488 | 1,192,842 | 0.0584 | Rupture |
| Average | 40,050 | 71,548 | 1,231,113 | 0.0542 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration**

Facing Researchers

Notes:

- 1) Reference D-74 to D-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-N40-FY09**
 Test Date: 5/15/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

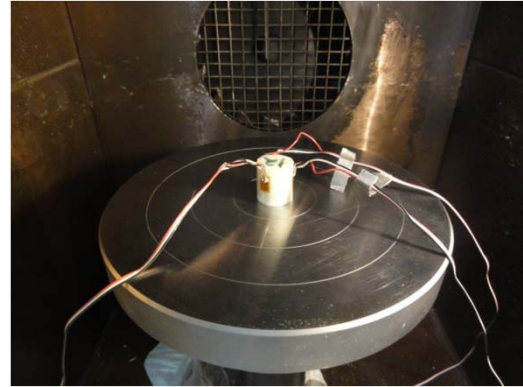
Average Material Properties:

Maximum Load, P_z : 42,712 lbs
 Compressive Strength, SC_z : 76,163 psi
 Compressive Modulus, E_z : 1,181,014 psi
 Ultimate Strain, ϵ_z : 0.043 in/in

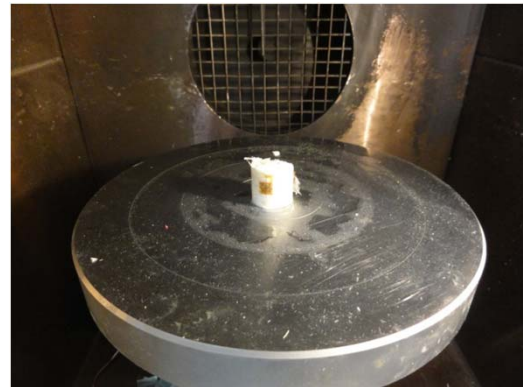
Measured Specimen Dimensions:

Thickness, T : 0.946 in
 Diameter, D : 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,542 psi
 50% Max Load: 21,356 psi

PICTURE OF SPECIMEN PRE-TEST



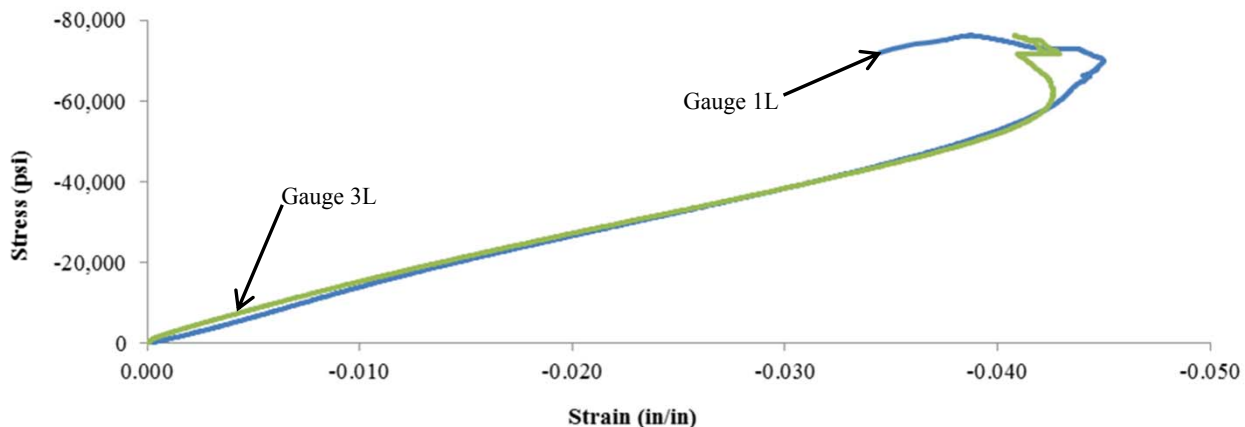
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02975 | 0.01085 | 1,208,812 |
| 2L | Lost Gauge | | |
| 3L | 0.02970 | 0.00989 | 1,153,217 |
| Average | | | 1,181,014 |

Stress-Strain Curve (09-01)_{-40°F_01}



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-N40-FY09**
 Test Date: 5/15/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 38,333 lbs
 Compressive Strength, SC_z : 68,518 psi
 Compressive Modulus, E_z : 1,274,654 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

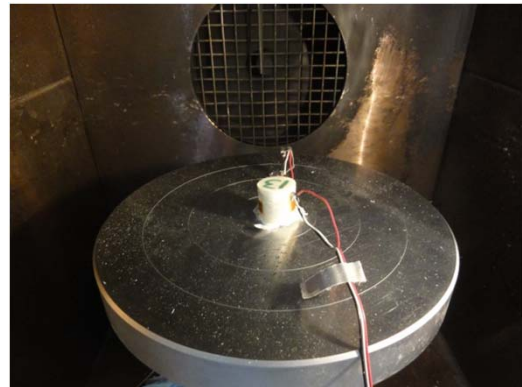
Measured Specimen Dimensions:

Thickness, T : 0.945 in
 Diameter, D : 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,667 psi
 50% Max Load: 19,167 psi

PICTURE OF SPECIMEN PRE-TEST



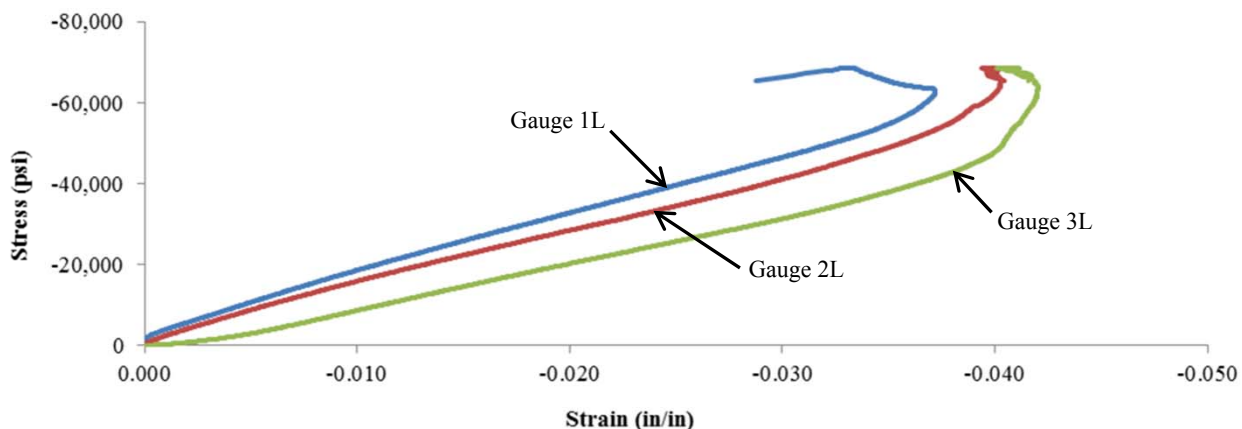
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02107 | 0.00682 | 1,442,005 |
| 2L | 0.02482 | 0.00838 | 1,250,198 |
| 3L | 0.03237 | 0.01421 | 1,131,758 |
| Average | | | 1,274,654 |

Stress-Strain Curve (09-01)_-40°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-N40-FY09**
 Test Date: 5/16/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 39,582 lbs
 Compressive Strength, SC_z : 70,582 psi
 Compressive Modulus, E_z : 1,172,459 psi
 Ultimate Strain, ϵ_z : 0.060 in/in

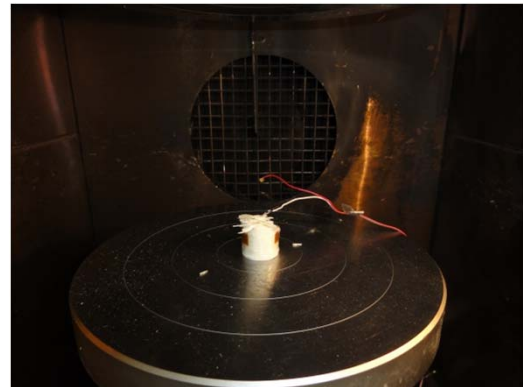
Measured Specimen Dimensions:

Thickness, T : 0.954 in
 Diameter, D : 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,916 psi
 50% Max Load: 19,791 psi

PICTURE OF SPECIMEN PRE-TEST



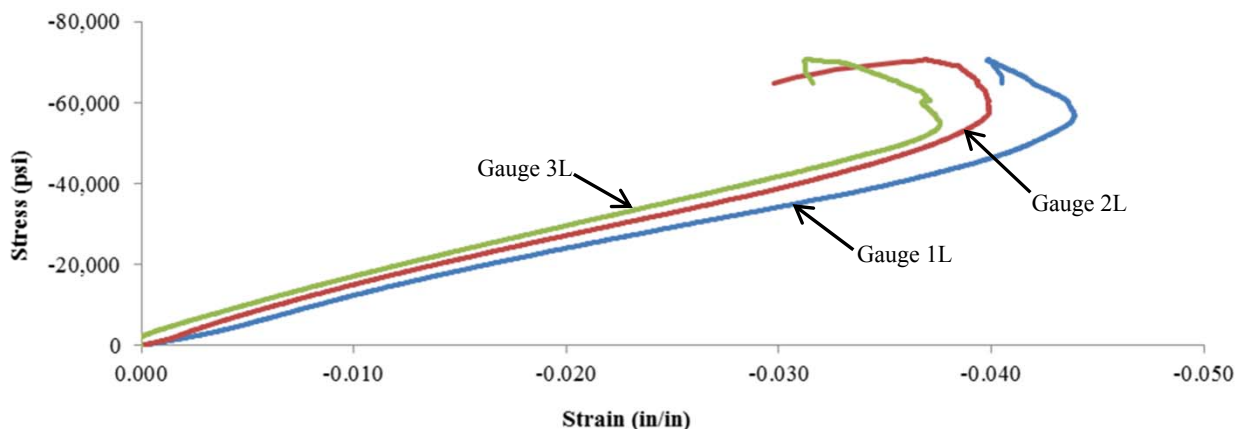
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03102 | 0.01132 | 1,075,013 |
| 2L | 0.02708 | 0.00930 | 1,190,811 |
| 3L | 0.02468 | 0.00776 | 1,251,552 |
| Average | | | 1,172,459 |

Stress-Strain Curve (09-01)_-40°F_03



Engineering Test notes:

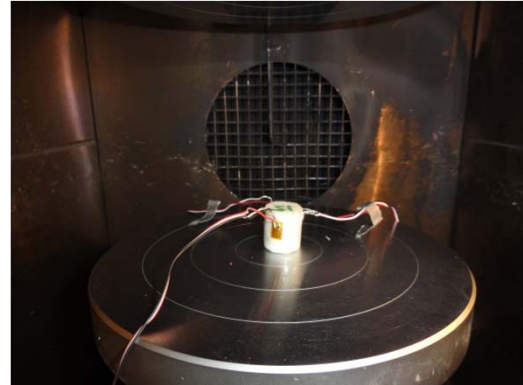
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

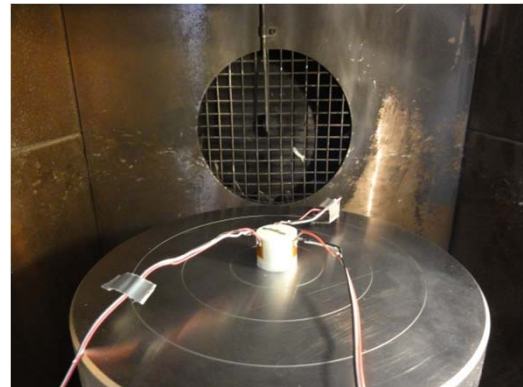
TEST SUMMARY

Specimen ID: **MAT1-CZ-04-N40-FY09**
 Test Date: 5/18/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Maximum Load, P_z : | 40,836 | lbs |
| Compressive Strength, SC_z : | 72,991 | psi |
| Compressive Modulus, E_z : | 1,334,594 | psi |
| Ultimate Strain, ϵ_z : | 0.055 | in/in |

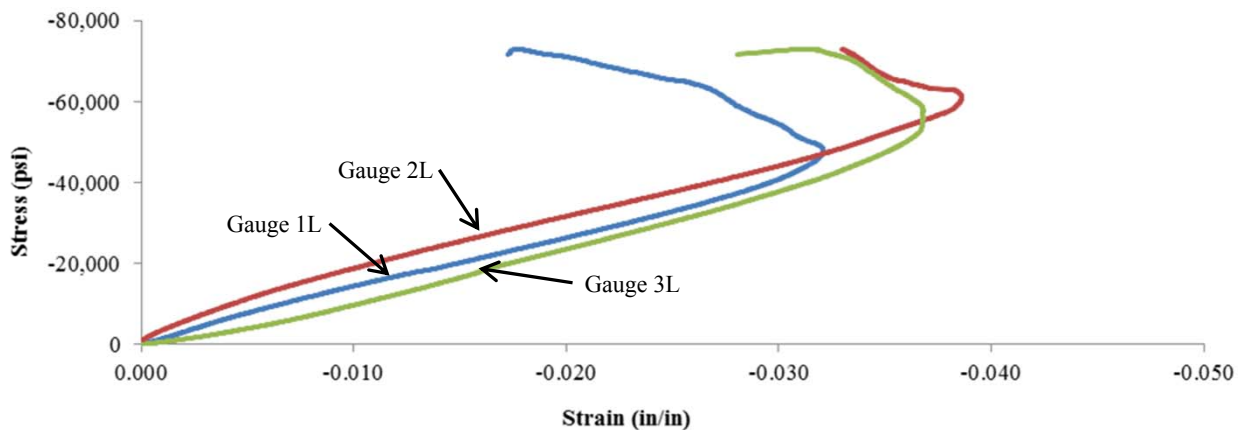
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 0.947 | in |
| Diameter, D: | 0.844 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 20% Max Load: | 8,167 | psi |
| 50% Max Load: | 20,418 | psi |

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02546 | 0.00796 | 1,251,575 |
| 2L | 0.02150 | 0.00531 | 1,352,547 |
| 3L | 0.02726 | 0.01161 | 1,399,660 |
| Average | | | 1,334,594 |

Stress-Strain Curve (09-01)_-40°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-N40-FY09**
 Test Date: 5/24/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

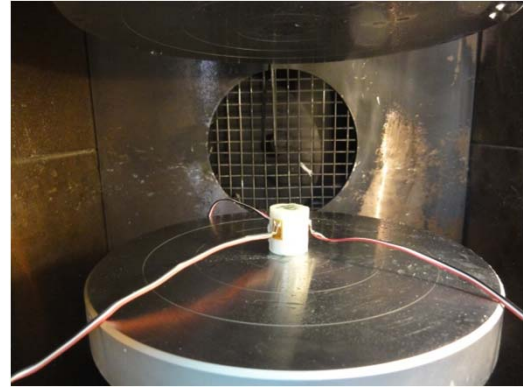
Average Material Properties:

Maximum Load, P_z : 38,784 lbs
 Compressive Strength, SC_z : 69,488 psi
 Compressive Modulus, E_z : 1,192,842 psi
 Ultimate Strain, ϵ_z : 0.058 in/in

Measured Specimen Dimensions:

Thickness, T: 0.949 in
 Diameter, D: 0.843 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,757 psi
 50% Max Load: 19,392 psi

PICTURE OF SPECIMEN PRE-TEST



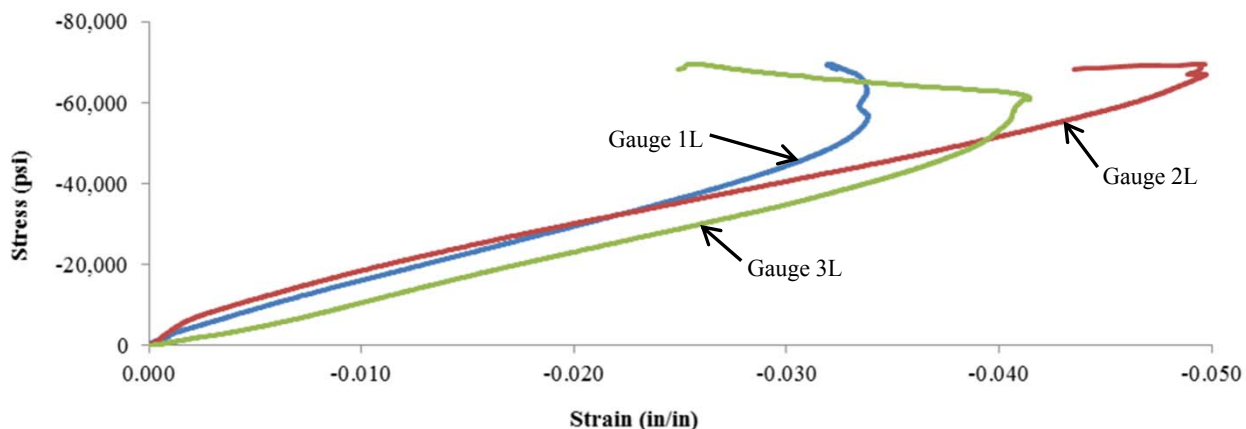
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02364 | 0.00748 | 1,290,061 |
| 2L | 0.02416 | 0.00583 | 1,137,276 |
| 3L | 0.02969 | 0.01158 | 1,151,190 |
| Average | | | 1,192,842 |

Stress-Strain Curve (09-01)_-40°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

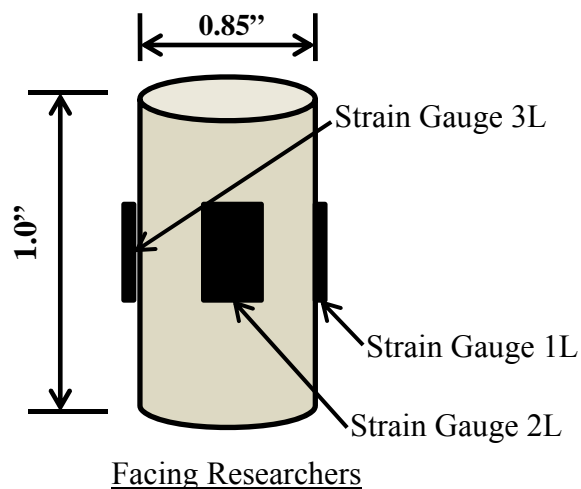
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-CZ-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_z , E_z , ϵ_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **32,396** **lbs**
 Compressive Strength, SC_z : **57,795** **psi**
 Compressive Modulus, E_z : **1,080,657** **psi**
 Ultimate Strain, ϵ_z : **0.056** **in/in**

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT1-CZ-01-70-FY09 | 32,239 | 57,488 | 950,140 | 0.0625 | Rupture |
| MAT1-CZ-02-70-FY09 | 31,898 | 57,014 | 908,138 | 0.0629 | Rupture |
| MAT1-CZ-03-70-FY09 | 31,980 | 56,892 | 1,022,781 | 0.0565 | Rupture |
| MAT1-CZ-04-70-FY09 | 32,266 | 57,673 | 1,416,957 | 0.0427 | Rupture |
| MAT1-CZ-05-70-FY09 | 33,597 | 59,910 | 1,105,267 | 0.0544 | Rupture |
| Average | 32,396 | 57,795 | 1,080,657 | 0.056 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference D-80 to D-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-70-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

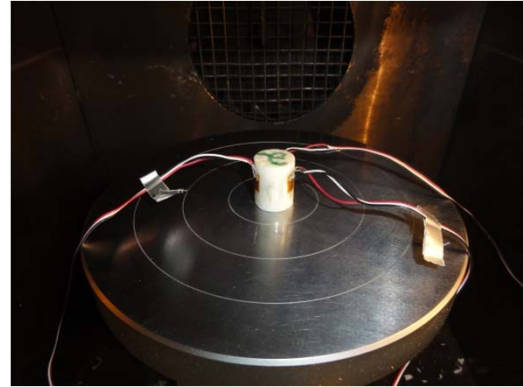
Average Material Properties:

Maximum Load, P_z : 32,239 lbs
 Compressive Strength, SC_z : 57,488 psi
 Compressive Modulus, E_z : 950,140 psi
 Ultimate Strain, ϵ_z : 0.062 in/in

Measured Specimen Dimensions:

Thickness, T: 1.062 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,448 psi
 50% Max Load: 16,119 psi

PICTURE OF SPECIMEN PRE-TEST



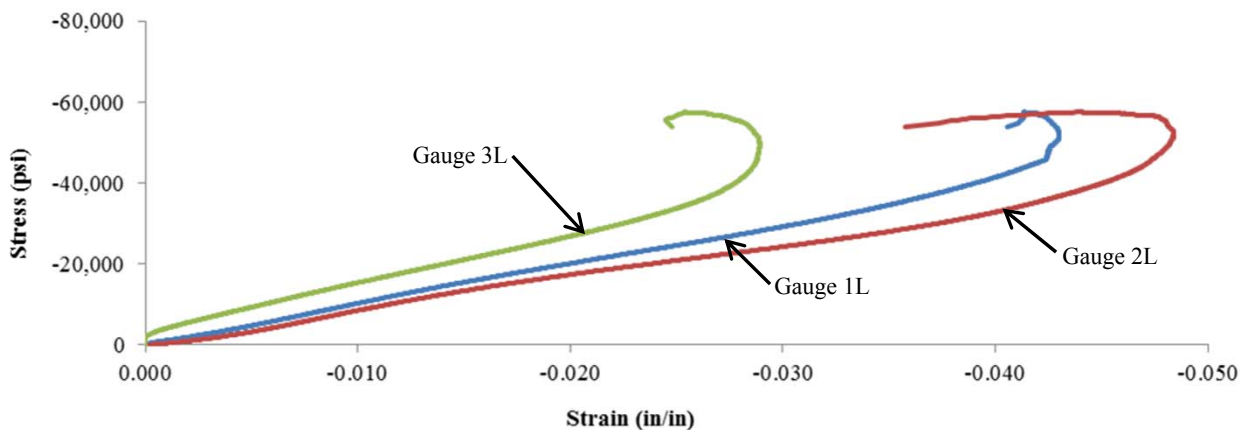
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02949 | 0.01105 | 935,125 |
| 2L | 0.03584 | 0.01288 | 751,098 |
| 3L | 0.02150 | 0.00669 | 1,164,198 |
| Average | | | 950,140 |

Stress-Strain Curve (09-01)_70°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-70-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

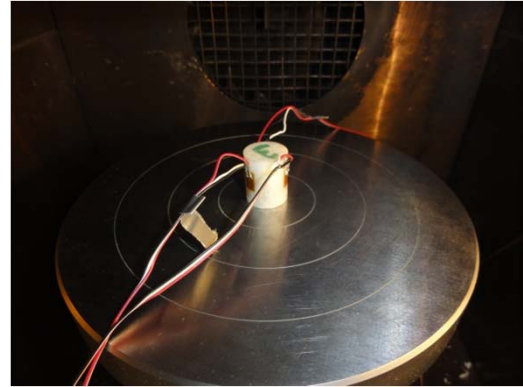
Average Material Properties:

Maximum Load, P_z : 31,898 lbs
 Compressive Strength, SC_z : 57,014 psi
 Compressive Modulus, E_z : 908,138 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

Measured Specimen Dimensions:

Thickness, T: 1.070 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,380 psi
 50% Max Load: 15,949 psi

PICTURE OF SPECIMEN PRE-TEST



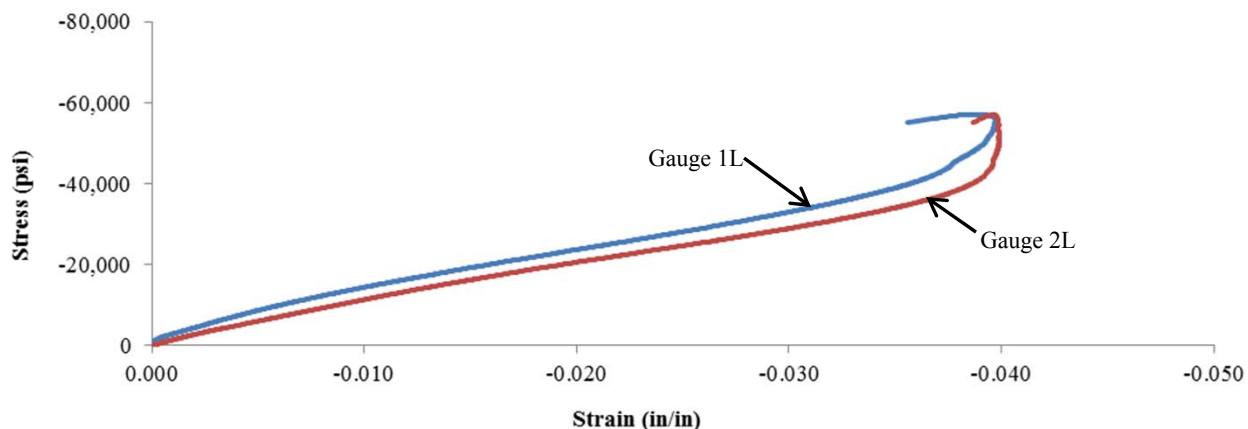
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02541 | 0.00721 | 939,717 |
| 2L | 0.02954 | 0.01003 | 876,559 |
| 3L | Lost Gauge | | |
| Average | | | 908,138 |

Stress-Strain Curve (09-01)_70°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-70-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

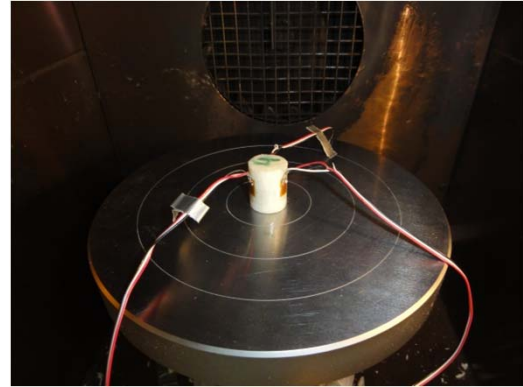
Average Material Properties:

Maximum Load, P_z : 31,980 lbs
 Compressive Strength, SC_z : 56,892 psi
 Compressive Modulus, E_z : 1,022,781 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured Specimen Dimensions:

Thickness, T: 1.065 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,396 psi
 50% Max Load: 15,990 psi

PICTURE OF SPECIMEN PRE-TEST



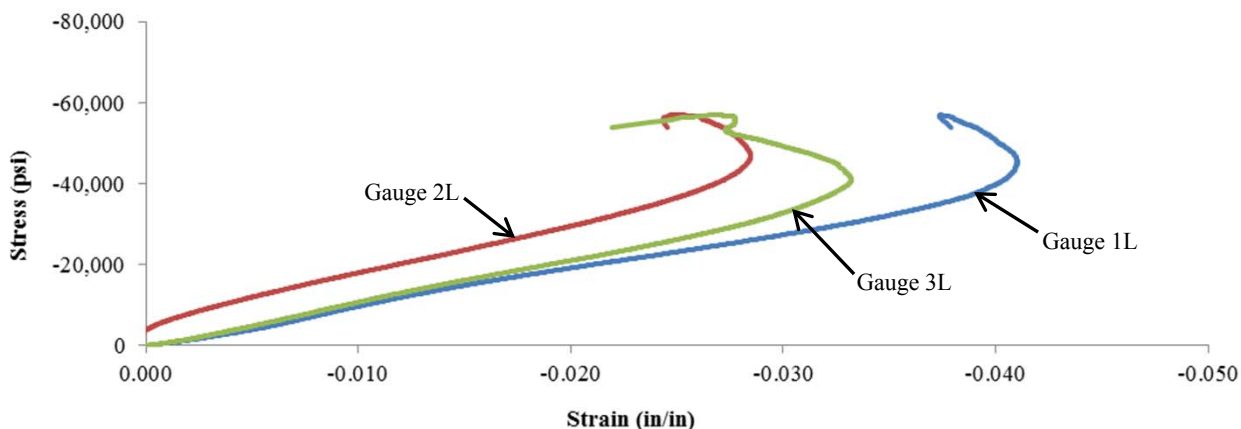
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03123 | 0.01146 | 863,371 |
| 2L | 0.01914 | 0.00450 | 1,165,772 |
| 3L | 0.02693 | 0.01050 | 1,039,201 |
| Average | | | 1,022,781 |

Stress-Strain Curve (09-01)_70°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-04-70-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

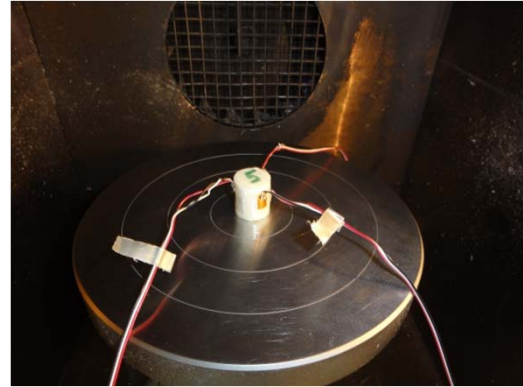
Average Material Properties:

Maximum Load, P_z : 32,266 lbs
 Compressive Strength, SC_z : 57,673 psi
 Compressive Modulus, E_z : 1,416,957 psi
 Ultimate Strain, ϵ_z : 0.043 in/in

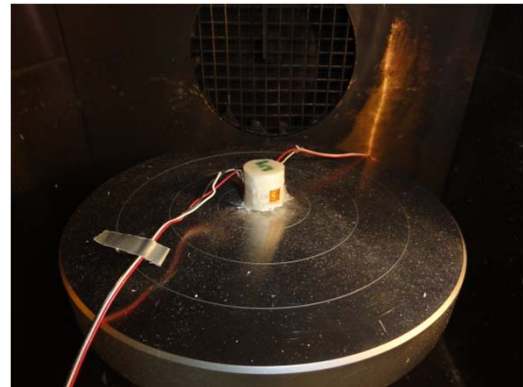
Measured Specimen Dimensions:

Thickness, T: 1.060 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,453 psi
 50% Max Load: 16,133 psi

PICTURE OF SPECIMEN PRE-TEST



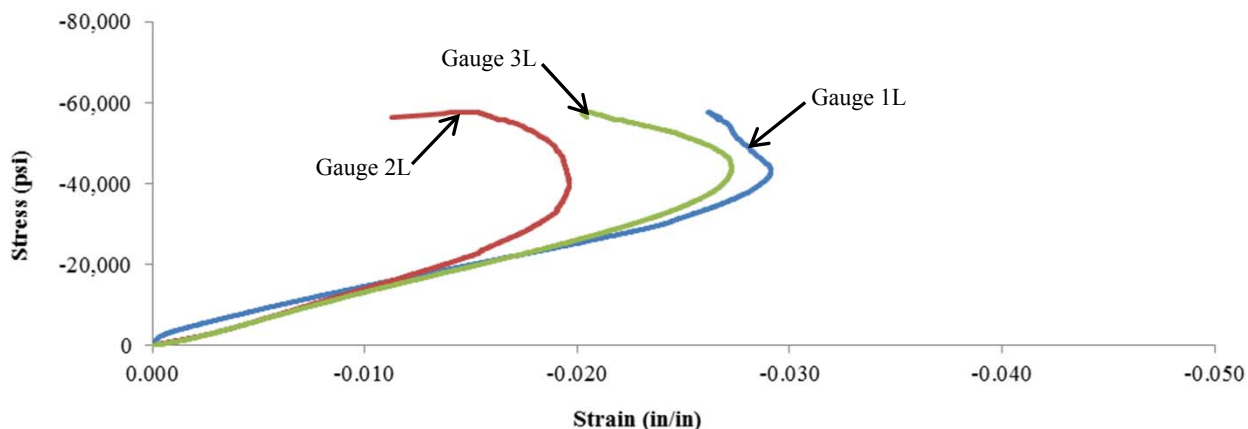
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02317 | 0.00723 | 1,085,351 |
| 2L | 0.01774 | 0.00837 | 1,845,883 |
| 3L | 0.02185 | 0.00874 | 1,319,638 |
| Average | | | 1,416,957 |

Stress-Strain Curve (09-01)_70°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-70-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

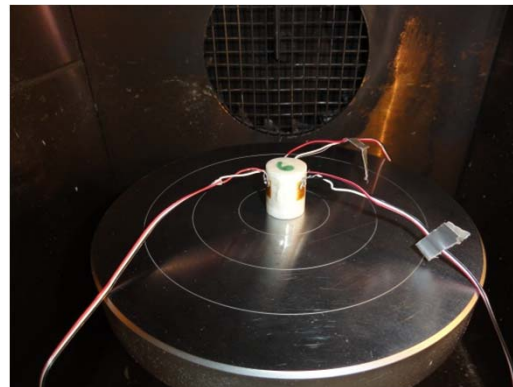
Average Material Properties:

Maximum Load, P_z : 33,597 lbs
 Compressive Strength, SC_z : 59,910 psi
 Compressive Modulus, E_z : 1,105,267 psi
 Ultimate Strain, ϵ_z : 0.054 in/in

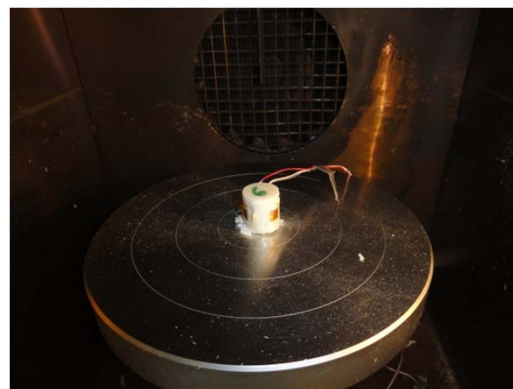
Measured Specimen Dimensions:

Thickness, T : 0.953 in
 Diameter, D : 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,719 psi
 50% Max Load: 16,799 psi

PICTURE OF SPECIMEN PRE-TEST



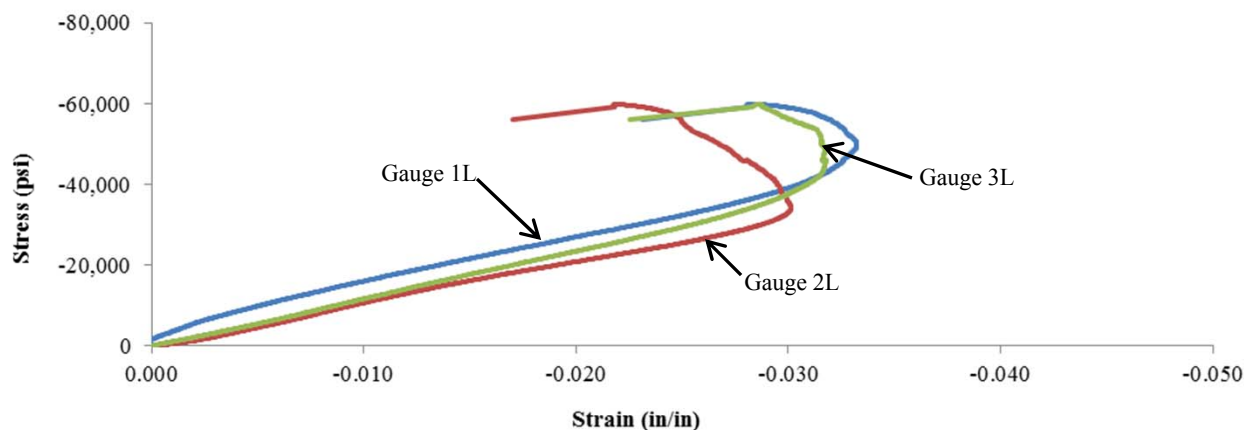
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02286 | 0.00662 | 1,107,103 |
| 2L | 0.02868 | 0.01110 | 1,022,478 |
| 3L | 0.02540 | 0.01025 | 1,186,219 |
| Average | | | 1,105,267 |

Stress-Strain Curve (09-01)_70°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

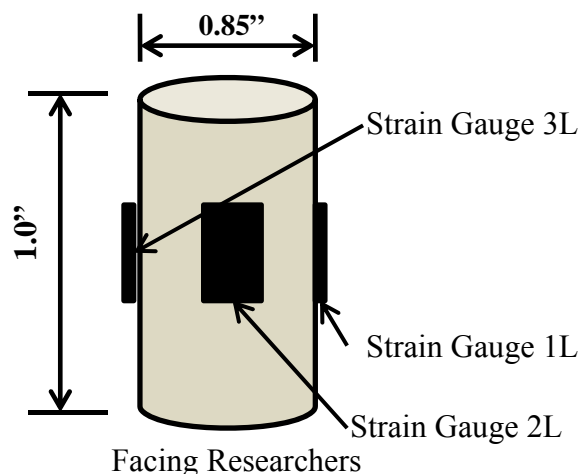
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-CZ-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 28,232 lbs
 Compressive Strength, SC_z : 50,439 psi
 Compressive Modulus, E_z : 1,174,700 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT1-CZ-01-140-FY09 | 28,542 | 50,896 | 1,151,705 | 0.0446 | Rupture |
| MAT1-CZ-02-140-FY09 | 28,839 | 51,548 | 1,413,046 | 0.0377 | Rupture |
| MAT1-CZ-03-140-FY09 | 28,042 | 50,241 | 1,202,847 | 0.0423 | Rupture |
| MAT1-CZ-04-140-FY09 | 27,959 | 49,975 | 1,199,772 | 0.0436 | Rupture |
| MAT1-CZ-05-140-FY09 | 27,778 | 49,533 | 906,130 | 0.0555 | Rupture |
| Average | 28,232 | 50,439 | 1,174,700 | 0.045 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference D-86 to D-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-01-140-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

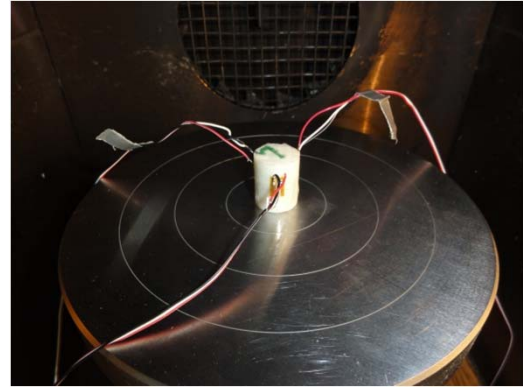
Average Material Properties:

Maximum Load, P_z : 28,542 lbs
 Compressive Strength, SC_z : 50,896 psi
 Compressive Modulus, E_z : 1,151,705 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

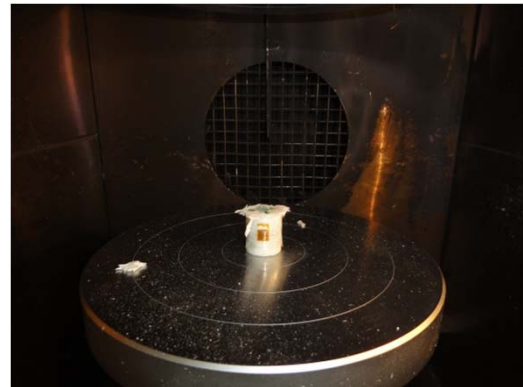
Measured Specimen Dimensions:

Thickness, T: 1.059 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,854 psi
 40% Max Load: 11,417 psi

PICTURE OF SPECIMEN PRE-TEST



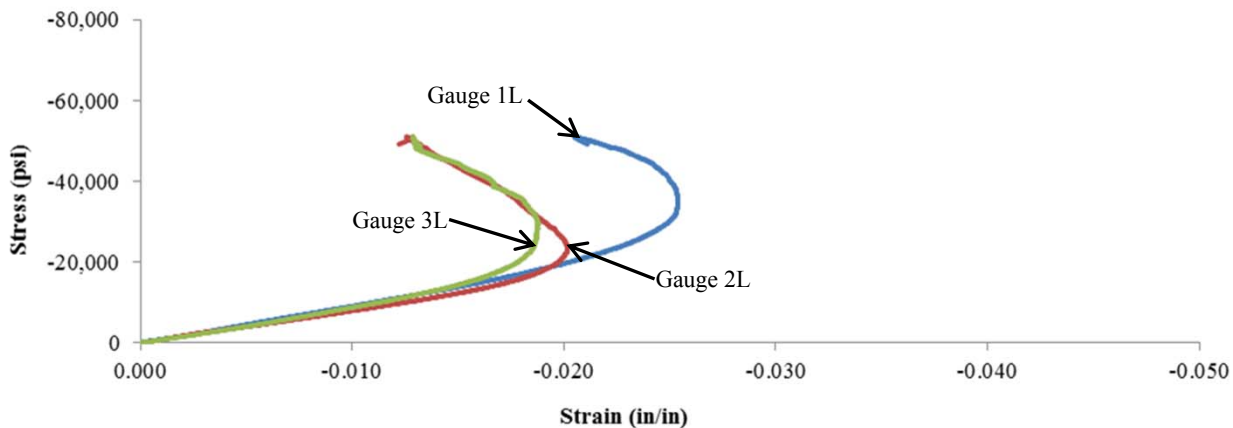
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02049 | 0.00559 | 1,025,028 |
| 2L | 0.01981 | 0.00636 | 1,135,485 |
| 3L | 0.01792 | 0.00612 | 1,294,601 |
| Average | | | 1,151,705 |

Stress-Strain Curve (09-01)_140°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-02-140-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

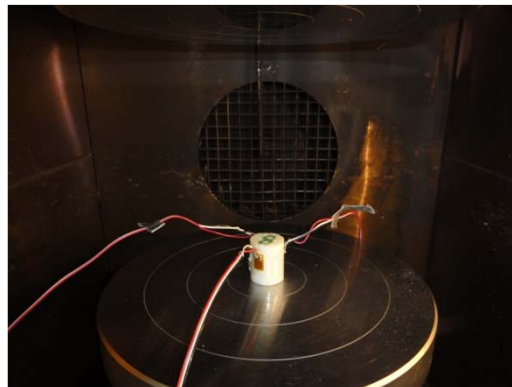
Average Material Properties:

Maximum Load, P_z : 28,839 lbs
 Compressive Strength, SC_z : 51,548 psi
 Compressive Modulus, E_z : 1,413,046 psi
 Ultimate Strain, ϵ_z : 0.038 in/in

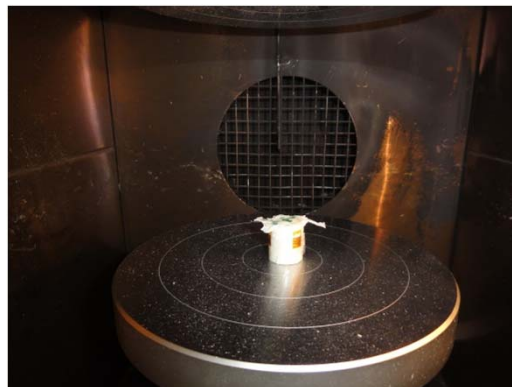
Measured Specimen Dimensions:

Thickness, T: 1.054 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,884 psi
 40% Max Load: 11,536 psi

PICTURE OF SPECIMEN PRE-TEST



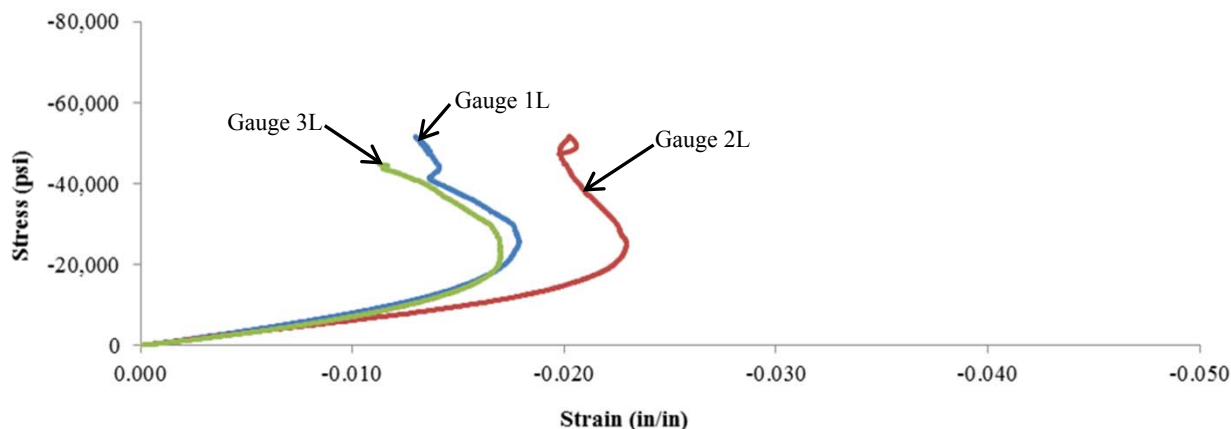
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 10% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.01728 | 0.00679 | 1,473,704 |
| 2L | 0.02246 | 0.00822 | 1,085,819 |
| 3L | 0.01693 | 0.00772 | 1,679,616 |
| Average | | | 1,413,046 |

Stress-Strain Curve (09-01)_140°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-03-140-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

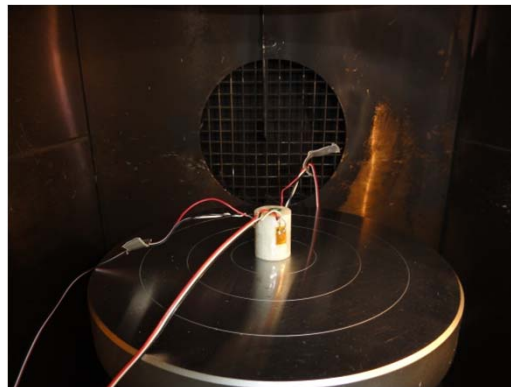
Average Material Properties:

Maximum Load, P_z : 28,042 lbs
 Compressive Strength, SC_z : 50,241 psi
 Compressive Modulus, E_z : 1,202,847 psi
 Ultimate Strain, ϵ_z : 0.042 in/in

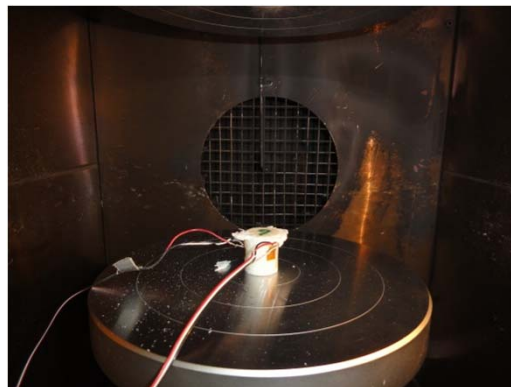
Measured Specimen Dimensions:

Thickness, T: 1.062 in
 Diameter, D: 0.843 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,804 psi
 40% Max Load: 11,217 psi

PICTURE OF SPECIMEN PRE-TEST



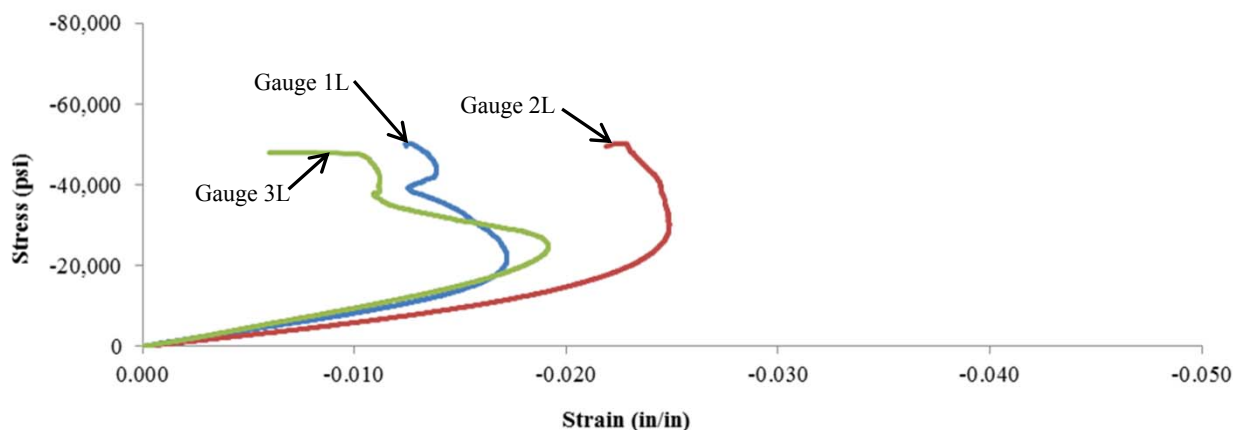
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.01711 | 0.00612 | 1,371,878 |
| 2L | 0.02305 | 0.00863 | 1,045,184 |
| 3L | 0.01802 | 0.00537 | 1,191,480 |
| Average | | | 1,202,847 |

Stress-Strain Curve (09-01)_140°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-04-140-FY09**
 Test Date: 5/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Maximum Load, P_z : | 27,959 | lbs |
| Compressive Strength, SC_z : | 49,975 | psi |
| Compressive Modulus, E_z : | 1,199,772 | psi |
| Ultimate Strain, ϵ_z : | 0.044 | in/in |

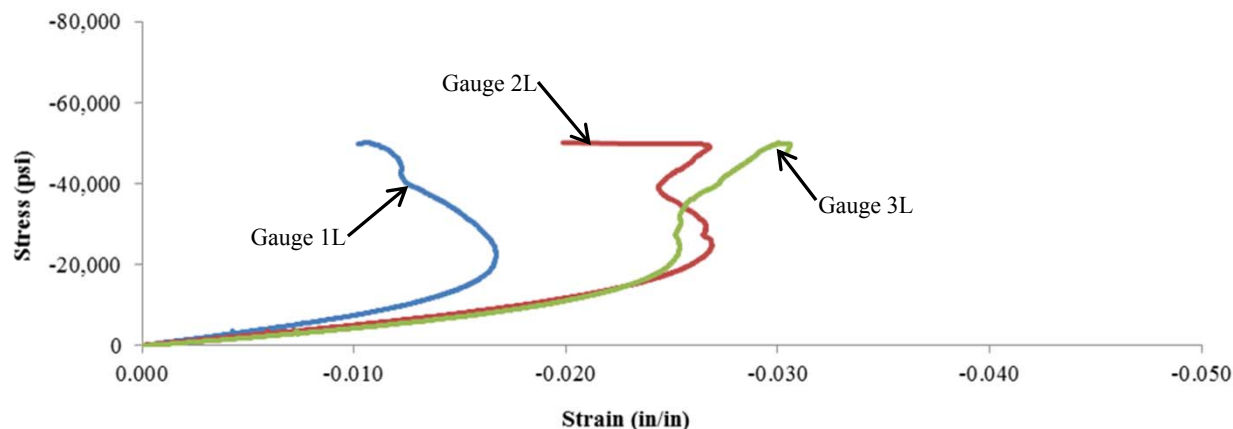
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 1.064 | in |
| Diameter, D: | 0.844 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 10% Max Load: | 2,796 | psi |
| 40% Max Load: | 11,184 | psi |

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 10% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.01661 | 0.00701 | 1,560,524 |
| 2L | 0.02590 | 0.00981 | 931,809 |
| 3L | 0.02491 | 0.01137 | 1,106,984 |
| Average | | | 1,199,772 |

Stress-Strain Curve (09-01)_140°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-CZ-05-140-FY09**
 Test Date: 5/15/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

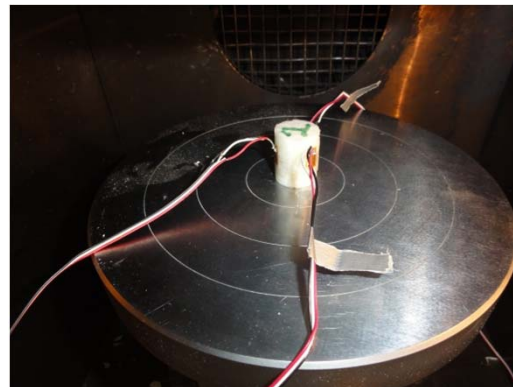
Average Material Properties:

Maximum Load, P_z : 27,778 lbs
 Compressive Strength, SC_z : 49,533 psi
 Compressive Modulus, E_z : 906,130 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured Specimen Dimensions:

Thickness, T: 1.056 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,778 psi
 40% Max Load: 11,111 psi

PICTURE OF SPECIMEN PRE-TEST



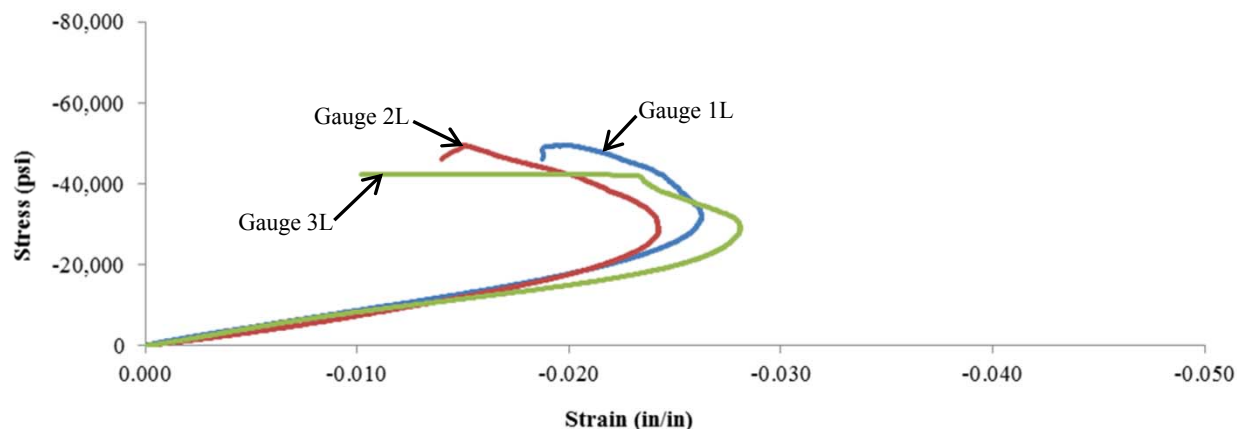
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02165 | 0.00540 | 914,129 |
| 2L | 0.02145 | 0.00713 | 1,037,388 |
| 3L | 0.02499 | 0.00561 | 766,873 |
| Average | | | 906,130 |

Stress-Strain Curve (09-01)_140°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

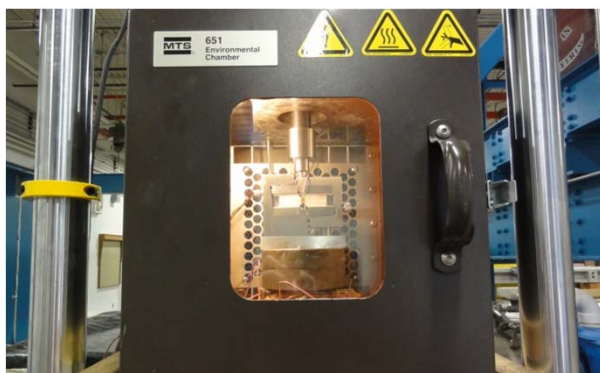
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-SXZ-N40-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **671** **lbs**
 Shear Strength, S_{xz} : **4,620** **psi**
 Shear Modulus, G_{xz} : **601,889** **psi**

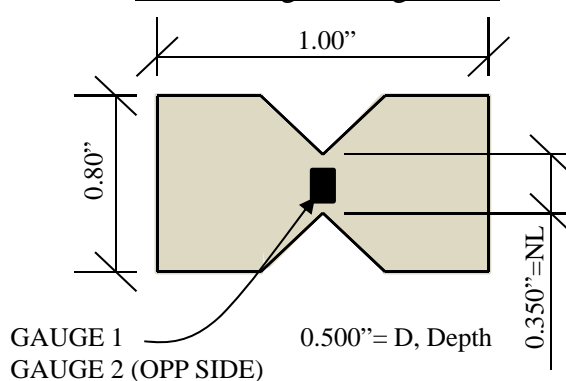
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT1-SXZ-01-N40-FY09 | 705 | 4,854 | 618,973 | Shear |
| MAT1-SXZ-02-N40-FY09 | 659 | 4,531 | 612,074 | Shear |
| MAT1-SXZ-03-N40-FY09 | 649 | 4,447 | 622,017 | Shear |
| MAT1-SXZ-04-N40-FY09 | 682 | 4,698 | 590,124 | Shear |
| MAT1-SXZ-05-N40-FY09 | 660 | 4,570 | 566,259 | Shear |
| Average | 671 | 4,620 | 601,889 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets D-92 to D-96
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-01-N40-FY09**
 Test Date: 8/31/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

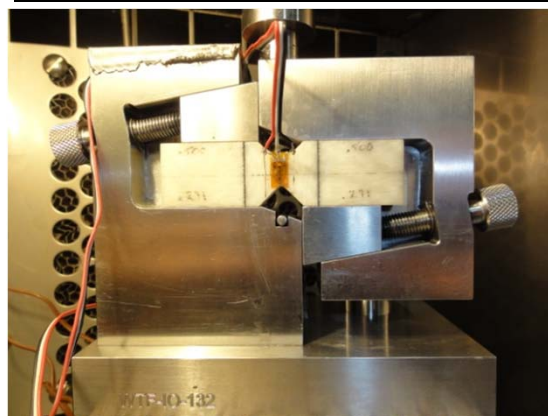
Average Material Properties:

Ultimate Load, P_{max} : **705** lbs
 Shear Strength, S_{xz} : **4,854** psi
 Shear Modulus, G_{xz} : **618,973** psi

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 352 lbs
 20% Max Load: 141 lbs

PICTURE OF SPECIMEN PRE-TEST



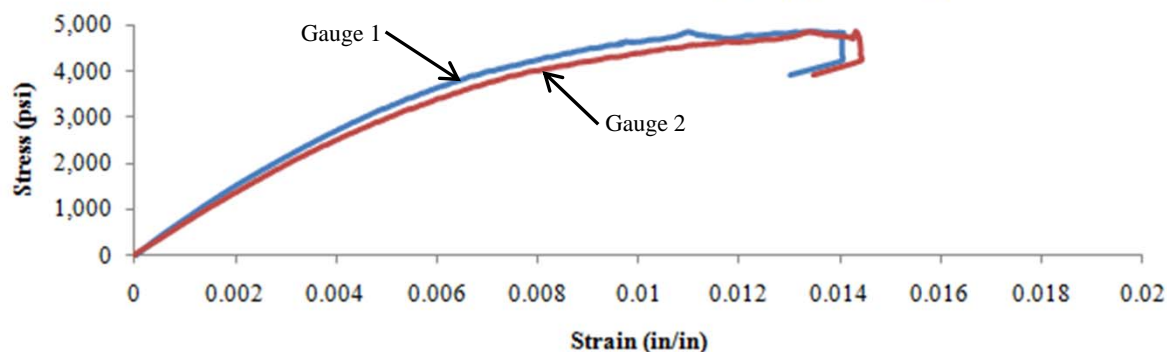
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.002972 | 0.000985 | 696,911 |
| 2 | 0.002796 | 0.001148 | 840,203 |
| Average | | | 768,557 |

Stress-Strain Curve -40°F_01_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-02-N40-FY09**
 Test Date: 9/1/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **659** lbs
 Shear Strength, S_{xz} : **4,531** psi
 Shear Modulus, G_{xz} : **612,074** psi

Measured Specimen Dimensions:

Depth, D: 0.500 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 330 lbs
 20% Max Load: 132 lbs

PICTURE OF SPECIMEN PRE-TEST



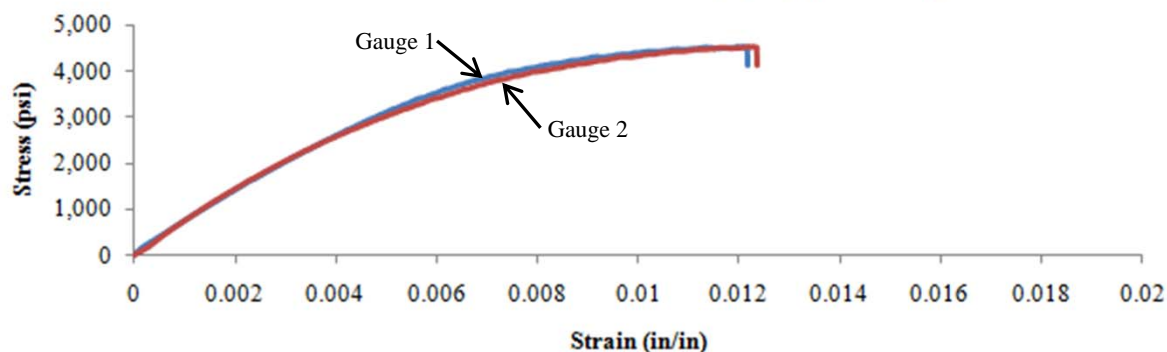
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0035 | 0.0012 | 612,321 |
| 2 | 0.0034 | 0.0012 | 611,827 |
| Average | | | 612,074 |

Stress-Strain Curve -40°F_02_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-03-N40-FY09**
 Test Date: 9/1/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **649** lbs
 Shear Strength, S_{xz} : **4,447** psi
 Shear Modulus, G_{xz} : **622,017** psi

Measured Specimen Dimensions:

Depth, D: 0.500 in
 Notch Length, NL: 0.292 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 325 lbs
 20% Max Load: 130 lbs

PICTURE OF SPECIMEN PRE-TEST



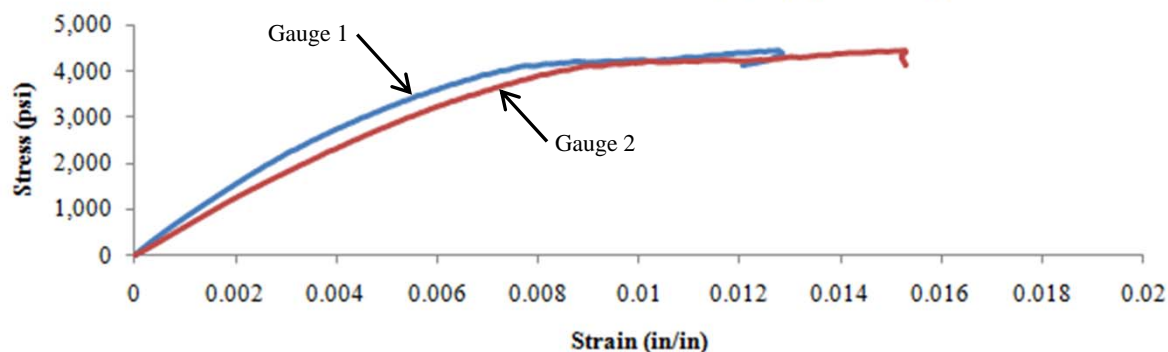
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0030 | 0.0011 | 682,736 |
| 2 | 0.0038 | 0.0014 | 561,298 |
| Average | | | 622,017 |

Stress-Strain Curve -40°F_03_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-04-N40-FY09**
 Test Date: 9/6/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

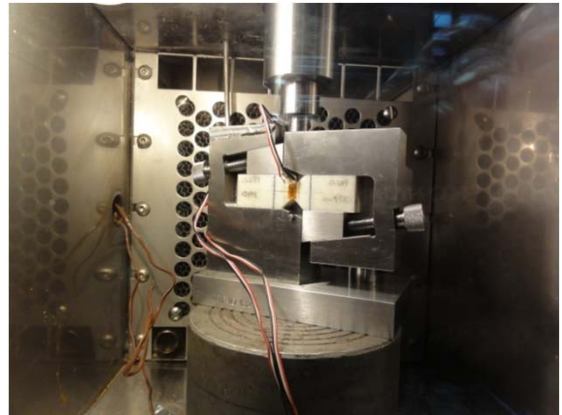
Average Material Properties:

Ultimate Load, P_{max} : **682** **lbs**
Shear Strength, S_{xz} : **4,698** **psi**
Shear Modulus, G_{xz} : **590,124** **psi**

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 341 lbs
 20% Max Load: 136 lbs

PICTURE OF SPECIMEN PRE-TEST



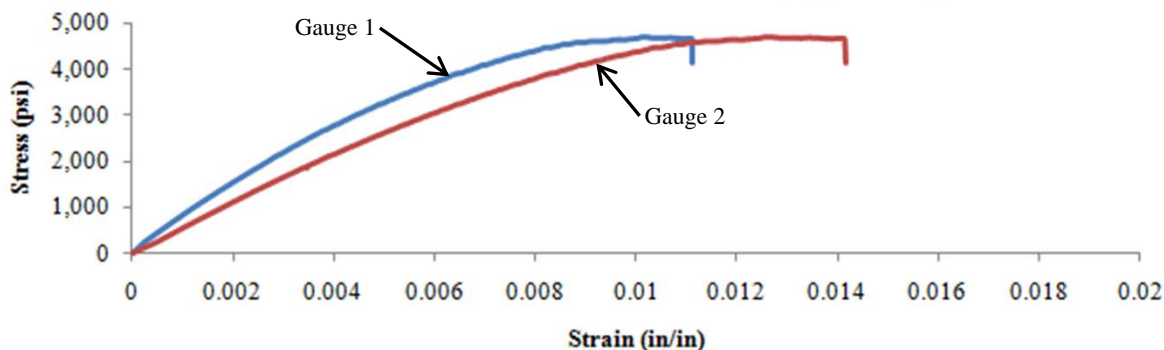
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0033 | 0.0011 | 665,389 |
| 2 | 0.0044 | 0.0017 | 514,859 |
| Average | | | 590,124 |

Stress-Strain Curve -40°F_04_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-05-N40-FY09**
 Test Date: 9/6/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **660** lbs
 Shear Strength, S_{xz} : **4,570** psi
 Shear Modulus, G_{xz} : **566,259** psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 330 lbs
 20% Max Load: 132 lbs

PICTURE OF SPECIMEN PRE-TEST



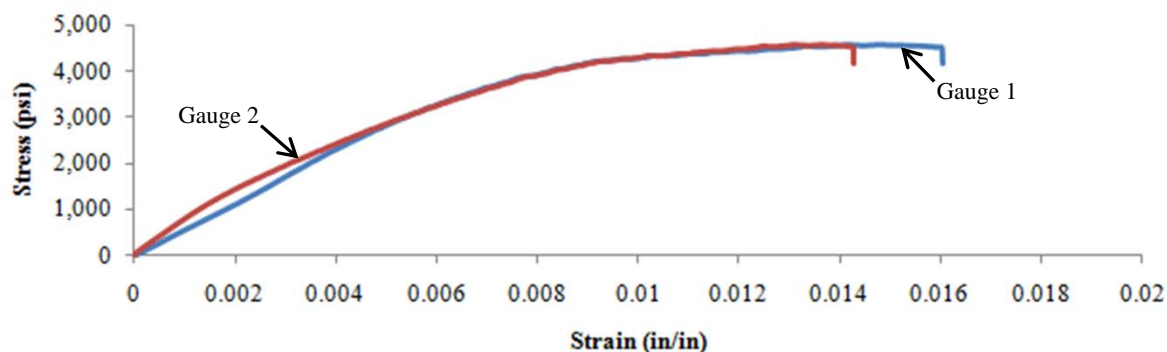
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0040 | 0.0017 | 594,739 |
| 2 | 0.0037 | 0.0012 | 537,778 |
| Average | | | 566,259 |

Stress-Strain Curve -40°F_05_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

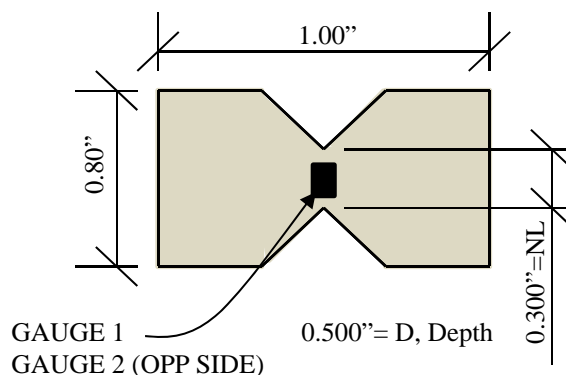
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT1-SXZ-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **394** **lbs**
 Shear Strength, S_{xz} : **2,720** **psi**
 Shear Modulus, G_{xz} : **460,711** **psi**

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT1-SXZ-01-70-FY09 | 419 | 2,896 | 523,719 | Shear |
| MAT1-SXZ-02-70-FY09 | 383 | 2,654 | 485,707 | Shear |
| MAT1-SXZ-03-70-FY09 | 382 | 2,632 | 418,427 | Shear |
| MAT1-SXZ-04-70-FY09 | 381 | 2,628 | 427,990 | Shear |
| MAT1-SXZ-05-70-FY09 | 403 | 2,789 | 447,710 | Shear |
| Average | 394 | 2,720 | 460,711 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets D-98 to D-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-01-70-FY09**
 Test Date: 9/8/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

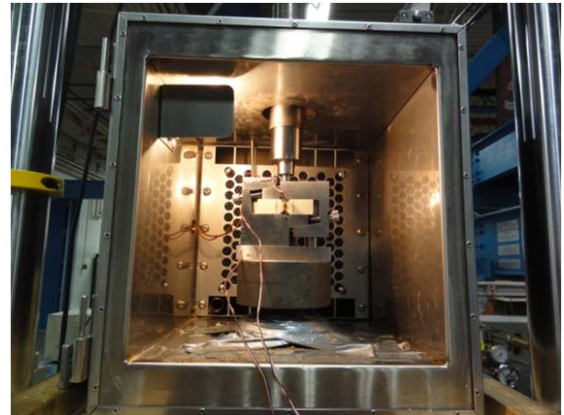
Average Material Properties:

Ultimate Load, P_{max} : **419** **lbs**
Shear Strength, S_{xz} : **2,896** **psi**
Shear Modulus, G_{xz} : **523,719** **psi**

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 210 lbs
 20% Max Load: 84 lbs

PICTURE OF SPECIMEN PRE-TEST



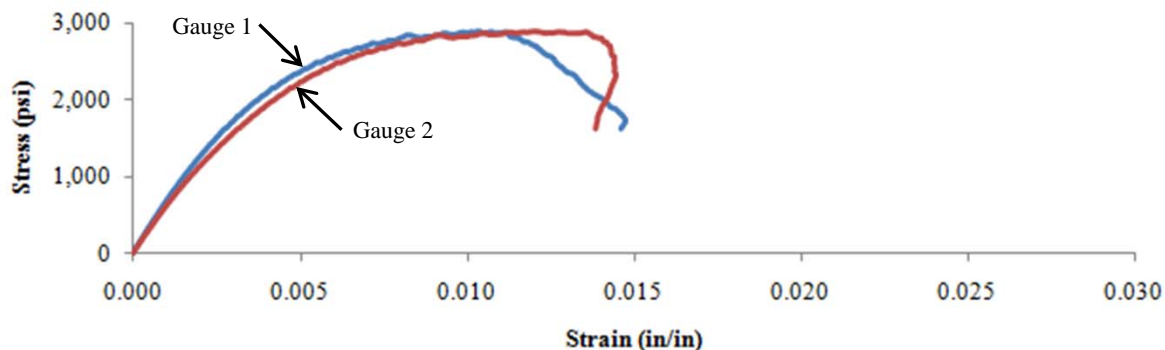
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0024 | 0.0008 | 561,490 |
| 2 | 0.0027 | 0.0009 | 485,948 |
| Average | | | 523,719 |

Stress-Strain Curve 70°F_01_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-02-70-FY09**
 Test Date: 9/8/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

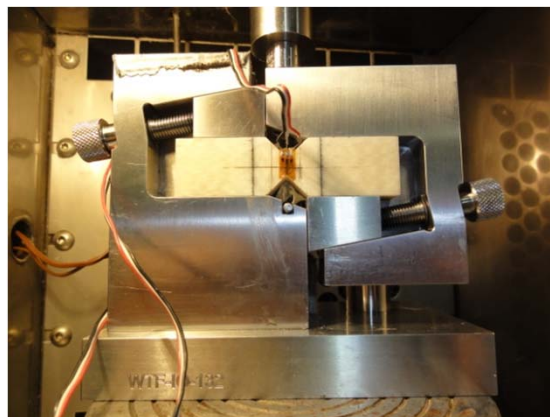
Average Material Properties:

Ultimate Load, P_{max} : **383** **lbs**
Shear Strength, S_{xz} : **2,654** **psi**
Shear Modulus, G_{xz} : **485,707** **psi**

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 192 lbs
 20% Max Load: 77 lbs

PICTURE OF SPECIMEN PRE-TEST



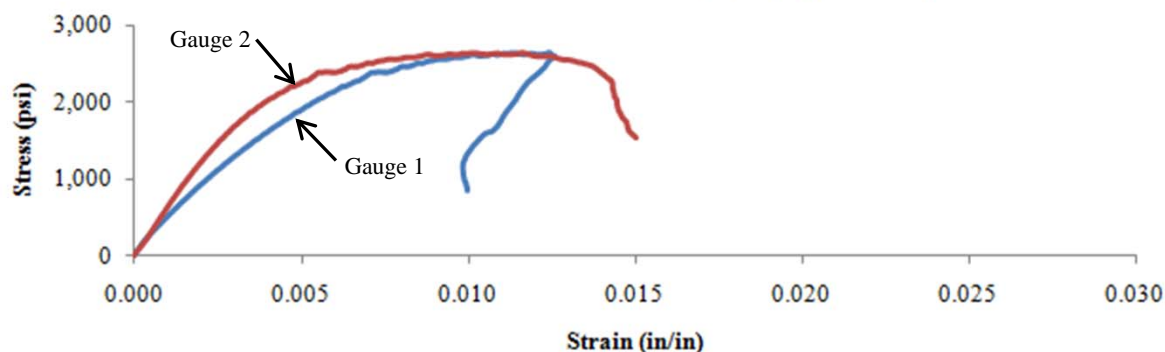
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0031 | 0.0010 | 387,749 |
| 2 | 0.0022 | 0.0008 | 583,665 |
| Average | | | 485,707 |

Stress-Strain Curve 70°F_02_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-03-70-FY09**
 Test Date: 9/8/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

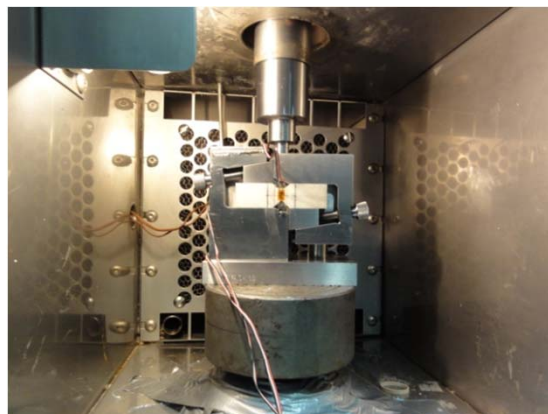
Average Material Properties:

Ultimate Load, P_{max} : **382** **lbs**
Shear Strength, S_{xz} : **2,632** **psi**
Shear Modulus, G_{xz} : **418,427** **psi**

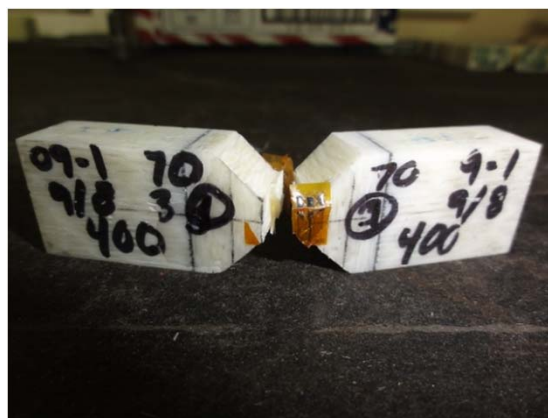
Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 191 lbs
 20% Max Load: 76 lbs

PICTURE OF SPECIMEN PRE-TEST



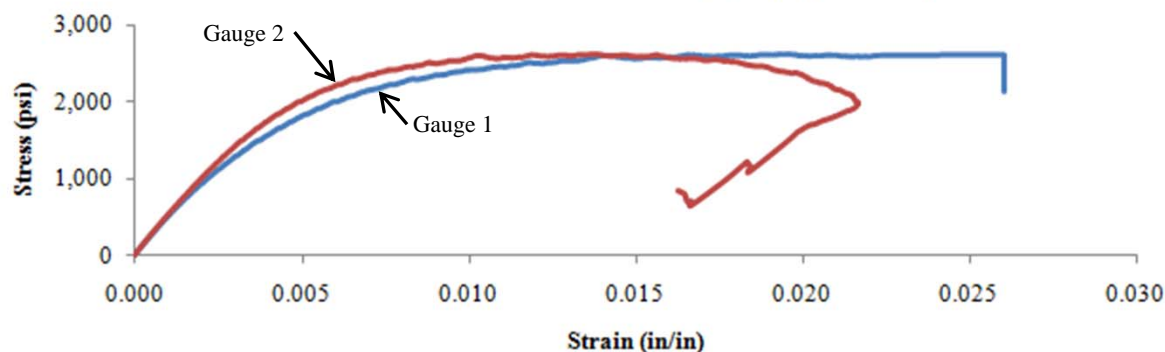
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0031 | 0.0010 | 382,076 |
| 2 | 0.0027 | 0.0010 | 454,777 |
| Average | | | 418,427 |

Stress-Strain Curve 70°F_03_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-04-70-FY09**
 Test Date: 9/8/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

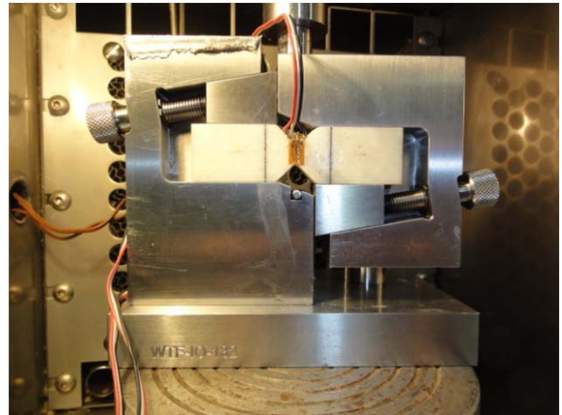
Average Material Properties:

Ultimate Load, P_{max} : 381 lbs
Shear Strength, S_{xz} : 2,628 psi
Shear Modulus, G_{xz} : 427,990 psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.291 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 190 lbs
 20% Max Load: 76 lbs

PICTURE OF SPECIMEN PRE-TEST



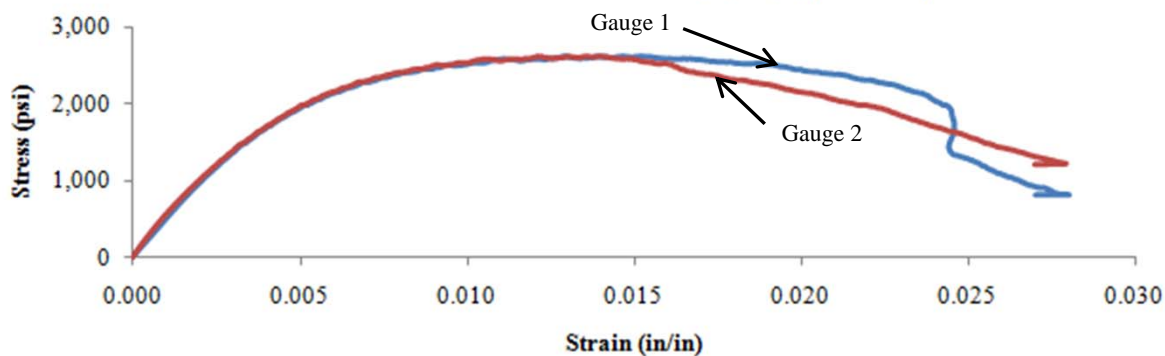
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0029 | 0.0010 | 434,036 |
| 2 | 0.0028 | 0.0009 | 421,944 |
| Average | | | 427,990 |

Stress-Strain Curve 70°F_04_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-05-70-FY09**
 Test Date: 9/8/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **403** **lbs**
Shear Strength, S_{xz} : **2,789** **psi**
Shear Modulus, G_{xz} : **447,710** **psi**

Measured Specimen Dimensions:

Depth, D: 0.500 in
 Notch Length, NL: 0.289 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 202 lbs
 20% Max Load: 81 lbs

PICTURE OF SPECIMEN PRE-TEST



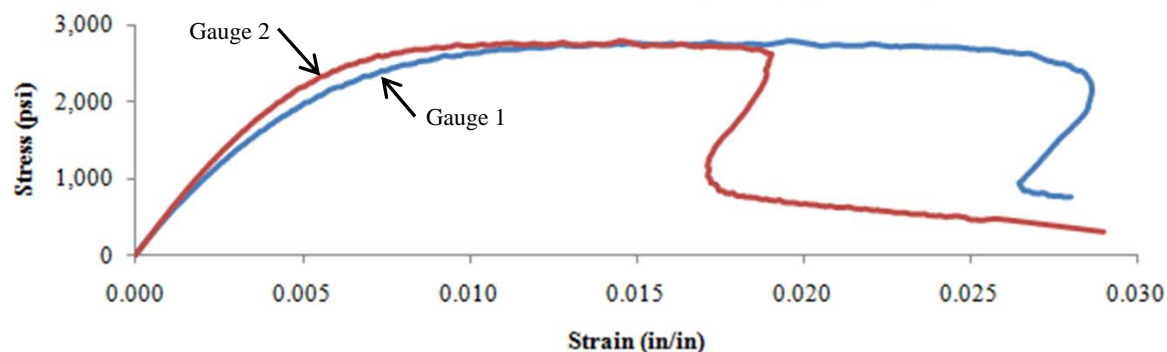
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0031 | 0.0011 | 407,824 |
| 2 | 0.0027 | 0.0010 | 487,597 |
| Average | | | 447,710 |

Stress-Strain Curve 70°F_05_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-SXZ-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: G_{xz} , S_{xz}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : 136 lbs
 Shear Strength, S_{xz} : 931 psi
 Shear Modulus, G_{xz} : 19,437 psi

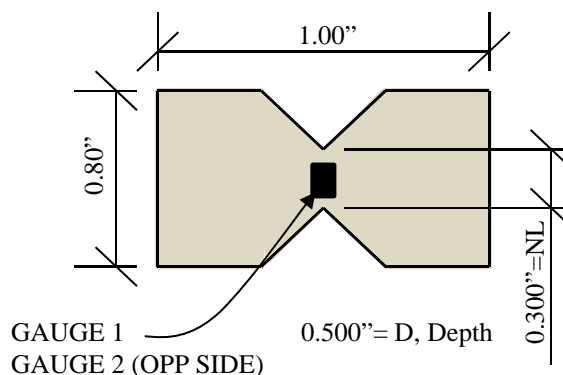
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT1-SXZ-01-140-FY09 | 129 | 881 | 25,292 | Shear |
| MAT1-SXZ-02-140-FY09 | 130 | 889 | 16,659 | Shear |
| MAT1-SXZ-03-140-FY09 | 139 | 951 | 21,009 | Shear |
| MAT1-SXZ-04-140-FY09 | 139 | 954 | 18,085 | Shear |
| MAT1-SXZ-05-140-FY09 | 143 | 981 | 16,138 | Shear |
| Average | 136 | 931 | 19,437 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets D-104 to D-108
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-01-140-FY09**
 Test Date: 9/6/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 129 lbs
Shear Strength, S_{xz} : 890 psi
Shear Modulus, G_{xz} : 25,569 psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 64 lbs
 20% Max Load: 26 lbs

PICTURE OF SPECIMEN PRE-TEST



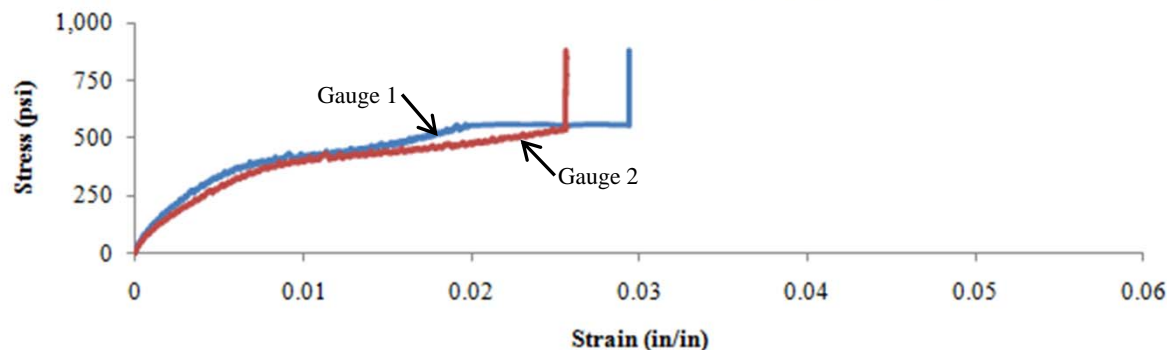
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0113 | 0.0018 | 28,037 |
| 2 | 0.0140 | 0.0024 | 23,101 |
| Average | | | 25,569 |

Stress-Strain Curve 140°F_01_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-02-140-FY09**
 Test Date: 9/6/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **130** lbs
 Shear Strength, S_{xz} : **902** psi
 Shear Modulus, G_{xz} : **16,900** psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.289 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 65 lbs
 20% Max Load: 26 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0204 | 0.0047 | 17,204 |
| 2 | 0.0212 | 0.0049 | 16,596 |
| Average | | | 16,900 |

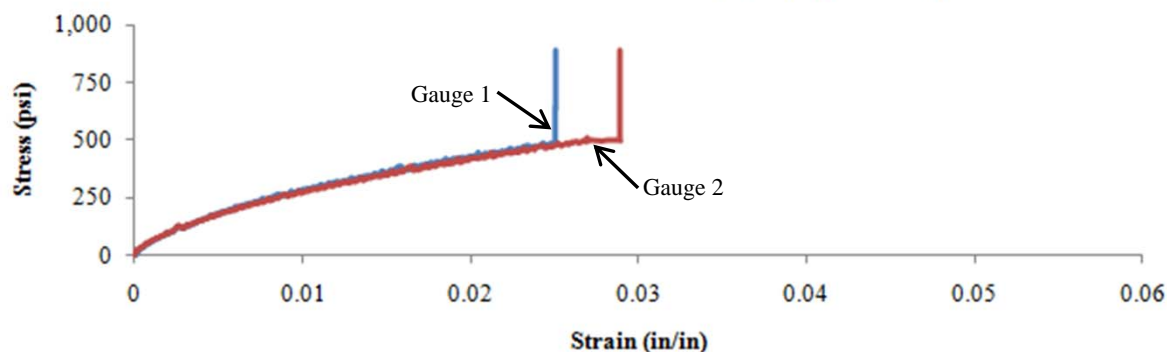
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140°F_02_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-03-140-FY09**
 Test Date: 9/7/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

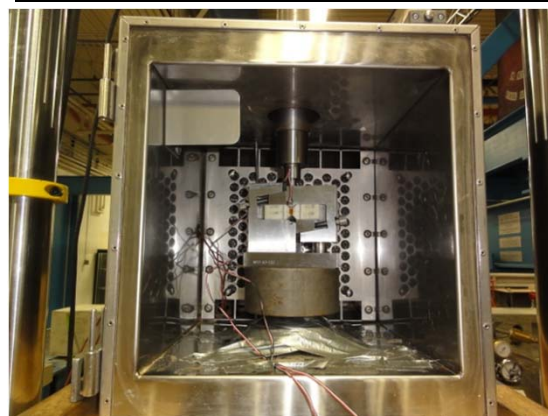
Average Material Properties:

Ultimate Load, P_{max} : 139 lbs
Shear Strength, S_{xz} : 960 psi
Shear Modulus, G_{xz} : 21,196 psi

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 69 lbs
 20% Max Load: 28 lbs

PICTURE OF SPECIMEN PRE-TEST



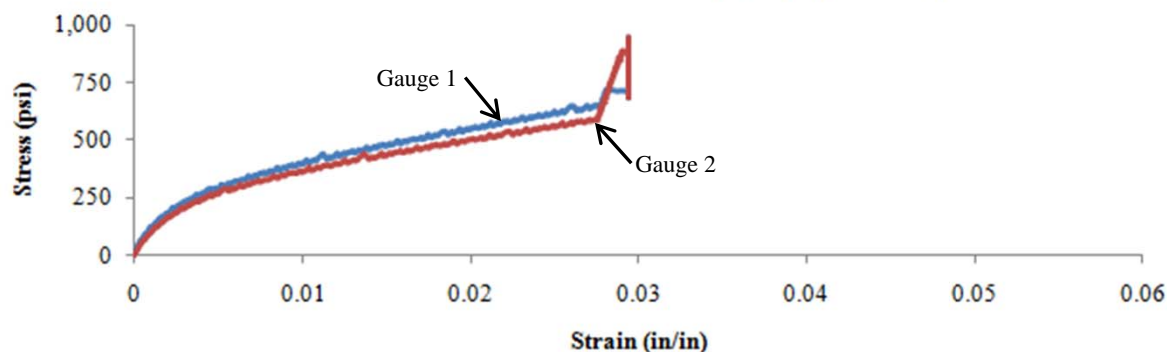
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0145 | 0.0021 | 23,232 |
| 2 | 0.0176 | 0.0026 | 19,161 |
| Average | | | 21,196 |

Stress-Strain Curve 140°F_03_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-04-140-FY09**
 Test Date: 9/7/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

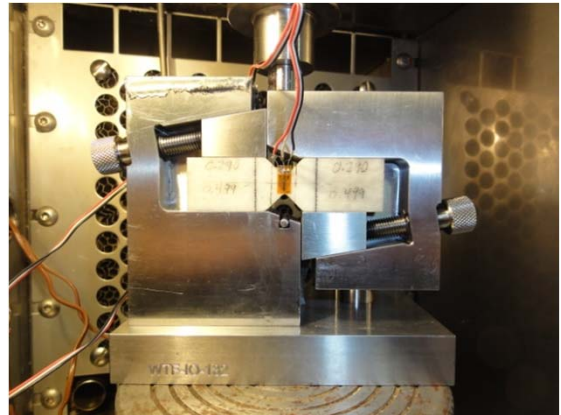
Average Material Properties:

Ultimate Load, P_{max} : 139 lbs
Shear Strength, S_{xz} : 969 psi
Shear Modulus, G_{xz} : 18,383 psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NL: 0.289 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 70 lbs
 20% Max Load: 28 lbs

PICTURE OF SPECIMEN PRE-TEST



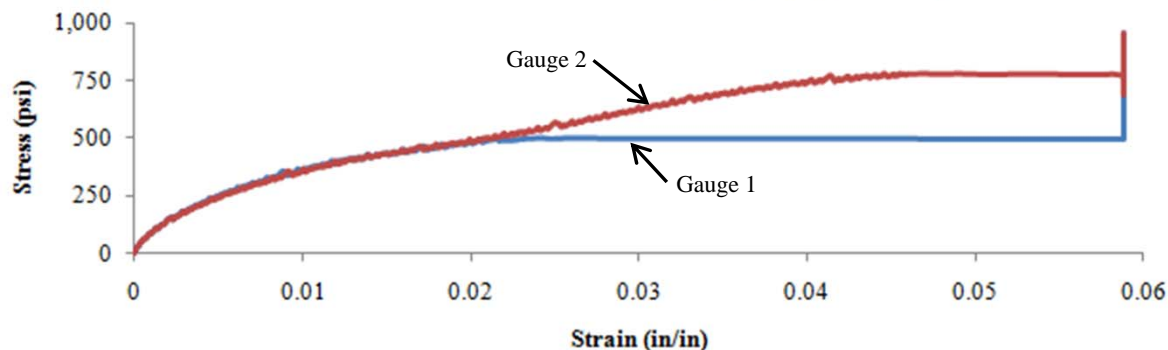
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0193 | 0.0032 | 18,083 |
| 2 | 0.0189 | 0.0033 | 18,683 |
| Average | | | 18,383 |

Stress-Strain Curve 140°F_04_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT1-SXZ-05-140-FY09**
 Test Date: 9/7/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

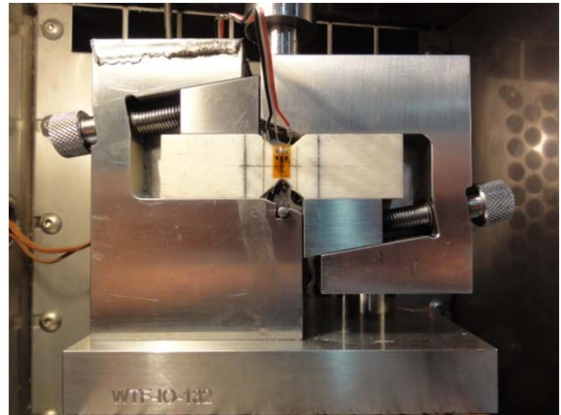
Average Material Properties:

Ultimate Load, P_{max} : 143 lbs
Shear Strength, S_{xz} : 1,002 psi
Shear Modulus, G_{xz} : 16,485 psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.287 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 72 lbs
 20% Max Load: 29 lbs

PICTURE OF SPECIMEN PRE-TEST



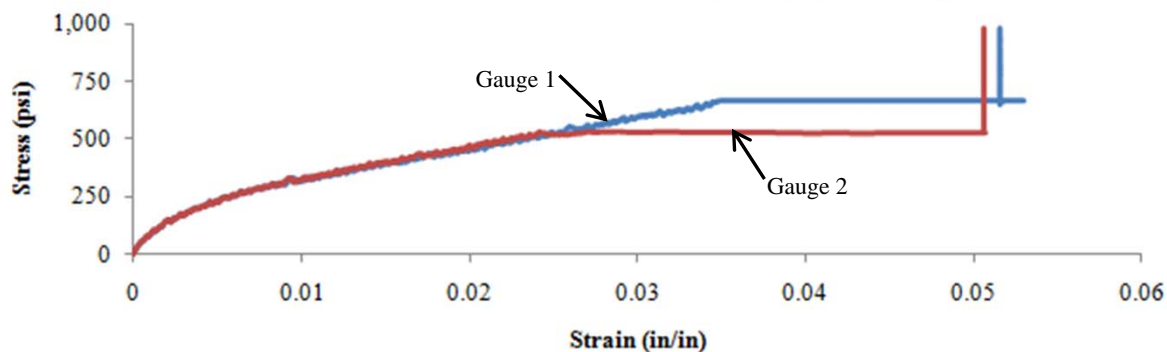
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0222 | 0.0035 | 16,129 |
| 2 | 0.0214 | 0.0036 | 16,841 |
| Average | | | 16,485 |

Stress-Strain Curve 140°F_05_(09-01)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

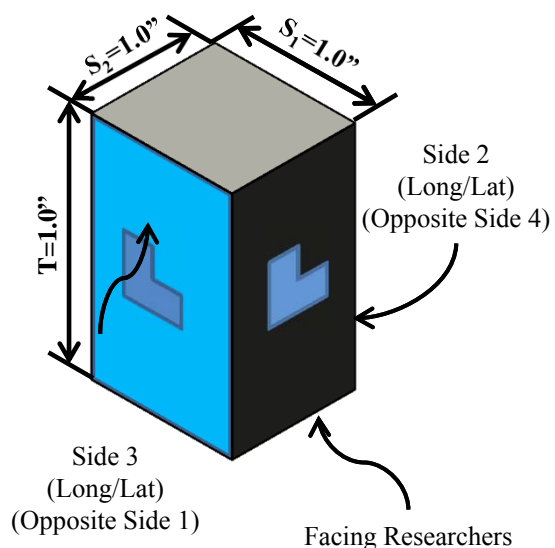
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-N40-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1576
 Maximum Load, P_z : 3,501 lbs

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|----------------------|-----------------------------|--------------|
| 1 | MAT1-OP-1-N40-FY09 | 3,600 | 0.1390 | Bondline |
| 2 | MAT1-OP-2-N40-FY09 | 3,233 | 0.1229 | Bondline |
| 3 | MAT1-OP-3-N40-FY09 | 3,335 | 0.2055 | Rupture |
| 4 | MAT1-OP-4-N40-FY09 | 3,371 | 0.1788 | Rupture |
| 5 | MAT1-OP-5-N40-FY09 | 3,967 | 0.1419 | Bondline |
| Average | | 3,501 | 0.1576 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference D-110 thru D-114 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-N40-FY09**
 Test Date: 9/26/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,600 lbs
 Poisson's Ratio, v_{xz} : 0.1390

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 0.983 in
 Side 2: 1.001 in

Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,800 lbs

20% Max Load: 720 lbs

PICTURE OF SPECIMEN PRE-TEST



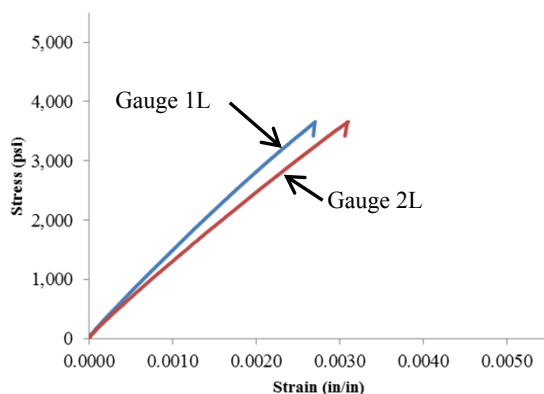
PICTURE OF SPECIMEN POST-TEST



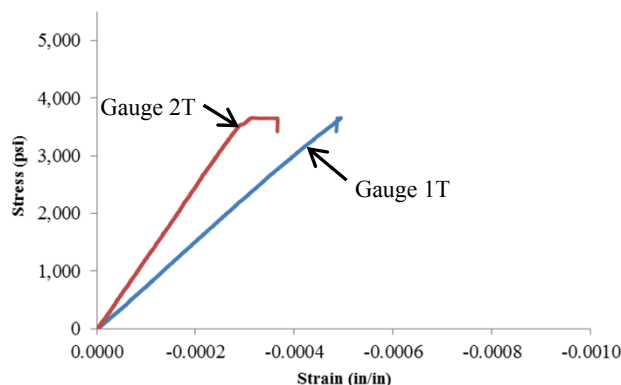
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001243 | 0.000460 | 1T | -0.000241 | -0.000099 | 0.1805 |
| 2L | 0.001440 | 0.000529 | 2T | -0.000149 | -0.000061 | 0.0975 |
| Average | | | | | | 0.1390 |

Stress-Strain Curve_N40_1_(09-01)_Long



Stress-Strain Curve_N40_1_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-N40-FY09**
 Test Date: 9/27/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,233 lbs
 Poisson's Ratio, v_{xz} : 0.1229

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.002 in
 Side 2: 1.005 in

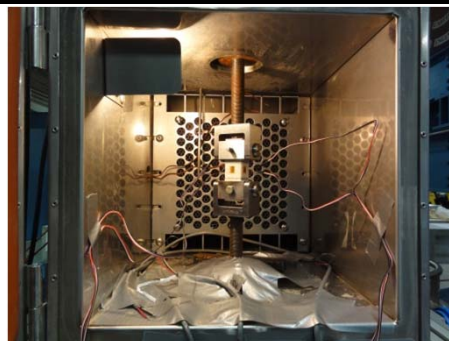
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,616 lbs

20% Max Load: 647 lbs

PICTURE OF SPECIMEN PRE-TEST



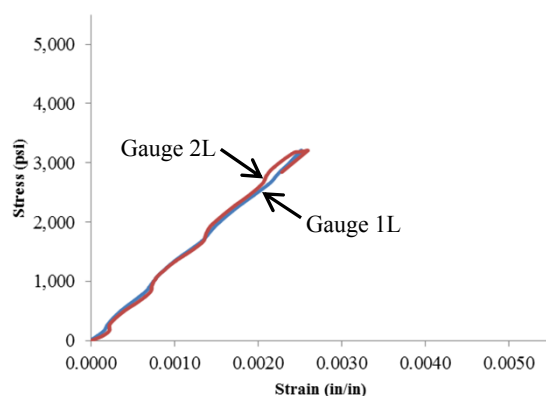
PICTURE OF SPECIMEN POST-TEST



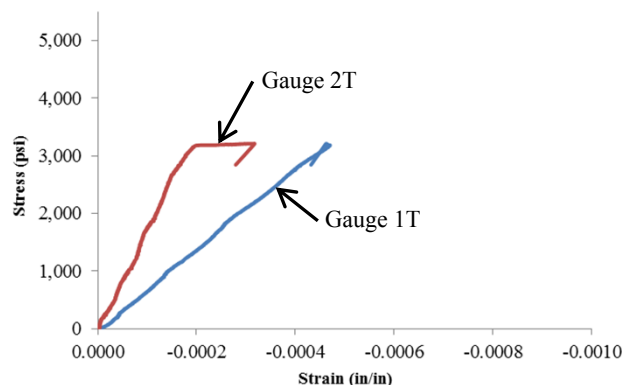
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001257 | 0.000484 | 1T | -0.000235 | -0.000100 | 0.1741 |
| 2L | 0.001286 | 0.000551 | 2T | -0.000093 | -0.000040 | 0.0716 |
| Average | | | | | | 0.1229 |

Stress-Strain Curve_N40_2_(09-01)_Long



Stress-Strain Curve_N40_2_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-N40-FY09**
 Test Date: 9/27/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,335 lbs
 Poisson's Ratio, v_{xz} : 0.2055

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.005 in
 Side 2: 1.006 in

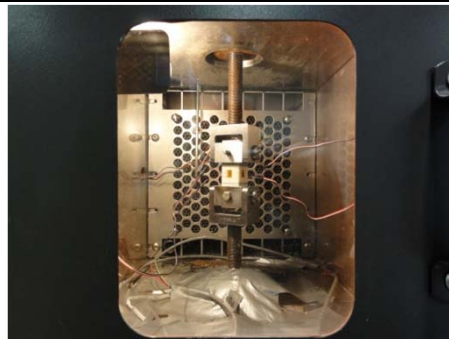
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,667 lbs

20% Max Load: 667 lbs

PICTURE OF SPECIMEN PRE-TEST



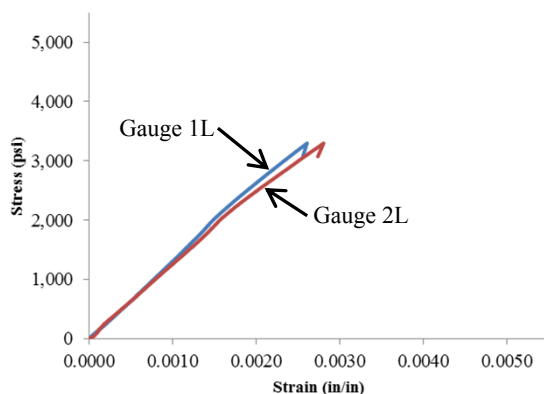
PICTURE OF SPECIMEN POST-TEST



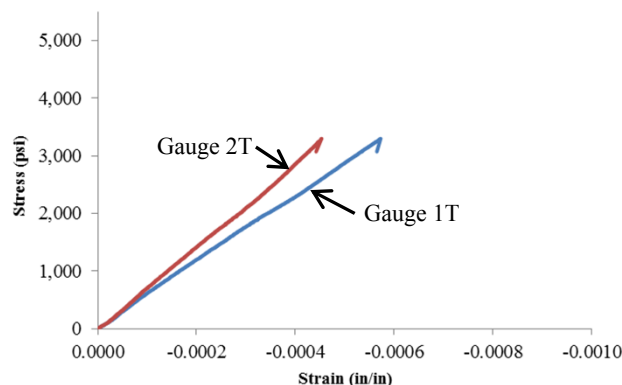
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001247 | 0.000520 | 1T | -0.000278 | -0.000107 | 0.2345 |
| 2L | 0.001315 | 0.000523 | 2T | -0.000233 | -0.000093 | 0.1765 |
| Average | | | | | | 0.2055 |

Stress-Strain Curve_N40_3_(09-01)_Long



Stress-Strain Curve_N40_3_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-N40-FY09**
 Test Date: 11/17/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,371 lbs
 Poisson's Ratio, v_{xz} : 0.1788

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 0.999 in
 Side 2: 1.001 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,686 lbs

20% Max Load: 674 lbs

PICTURE OF SPECIMEN PRE-TEST



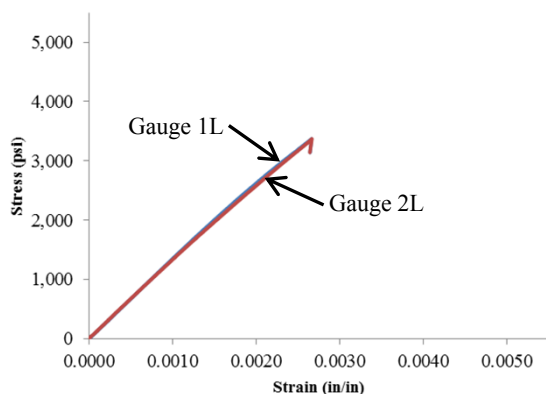
PICTURE OF SPECIMEN POST-TEST



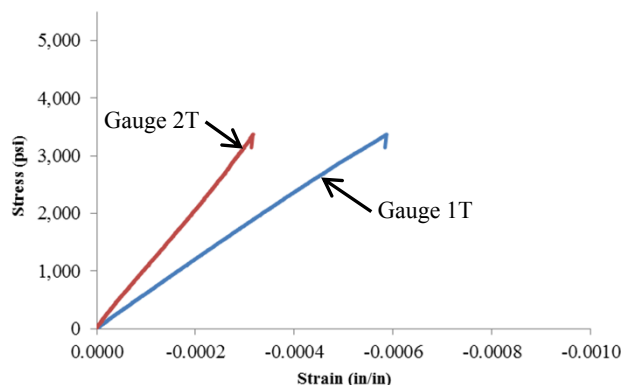
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001252 | 0.000502 | 1T | -0.000280 | -0.000110 | 0.2273 |
| 2L | 0.001273 | 0.000499 | 2T | -0.000162 | -0.000061 | 0.1304 |
| Average | | | | | | 0.1788 |

Stress-Strain Curve_N40_4_(09-01)_Long



Stress-Strain Curve_N40_4_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-N40-FY09**
 Test Date: 11/17/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

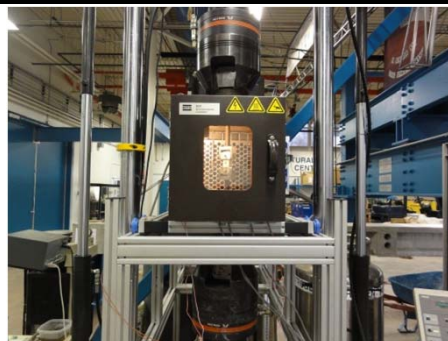
Average Material Properties:

Maximum Load, P_z : 3,967 lbs
 Poisson's Ratio, v_{xz} : 0.1419

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 0.999 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,984 lbs
 20% Max Load: 793 lbs

PICTURE OF SPECIMEN PRE-TEST



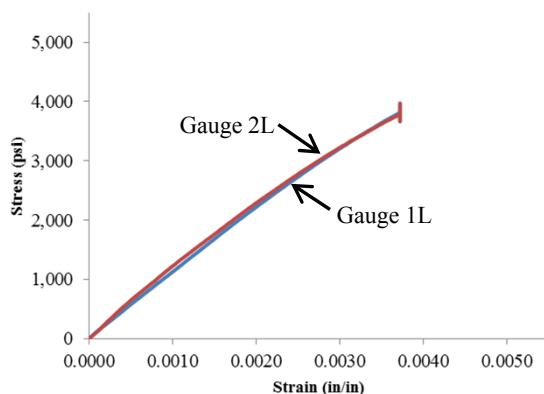
PICTURE OF SPECIMEN POST-TEST



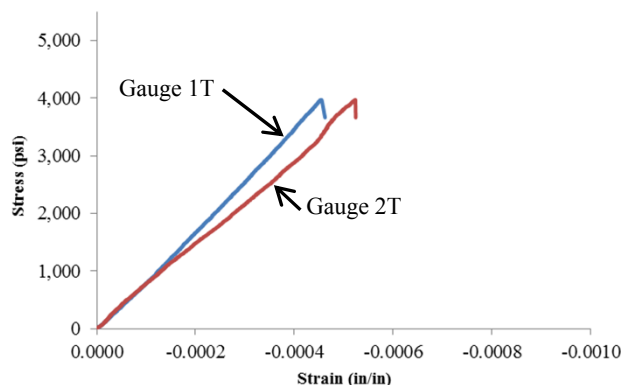
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001778 | 0.000695 | 1T | -0.000237 | -0.000101 | 0.1249 |
| 2L | 0.001709 | 0.000625 | 2T | -0.000274 | -0.000102 | 0.1590 |
| Average | | | | | | 0.1419 |

Stress-Strain Curve_N40_5_(09-01)_Long



Stress-Strain Curve_N40_5_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 70°F

Properties Measured:

Average Material Properties (5 Specimens):

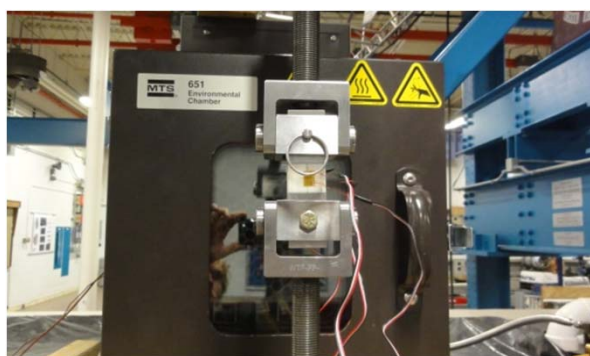
Poisson’s Ratio, ν_{xz} : 0.1365

Maximum Load, P_z : 2,649 lbs

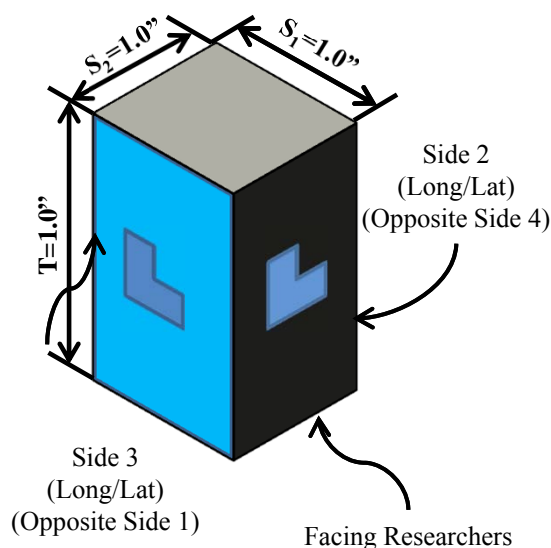
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|-------------------|----------------------|-----------------------------|--------------|
| 1 | MAT1-OP-1-70-FY09 | 2,624 | 0.1294 | Rupture |
| 2 | MAT1-OP-2-70-FY09 | 2,806 | 0.1609 | Rupture |
| 3 | MAT1-OP-3-70-FY09 | 2,395 | 0.1390 | Bondline |
| 4 | MAT1-OP-4-70-FY09 | 2,413 | 0.1432 | Bondline |
| 5 | MAT1-OP-5-70-FY09 | 3,007 | 0.1101 | Bondline |
| Average | | 2,649 | 0.1365 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) Reference D-116 thru D-120 for individual specimen data.
- 2) 6 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-70-FY09**
 Test Date: 9/22/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 2,624 lbs
 Poisson's Ratio, v_{xz} : 0.1294

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.000 in
 Side 2: 0.999 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,312 lbs

20% Max Load: 525 lbs

PICTURE OF SPECIMEN PRE-TEST



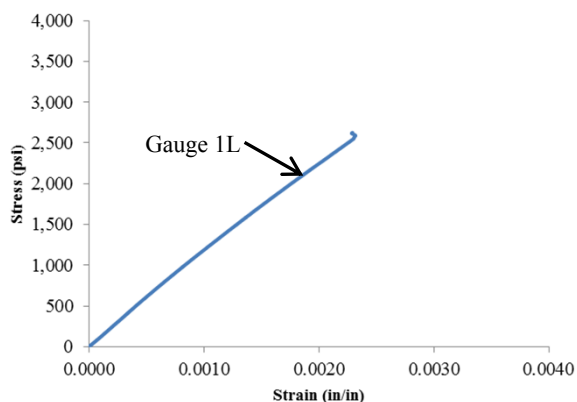
PICTURE OF SPECIMEN POST-TEST



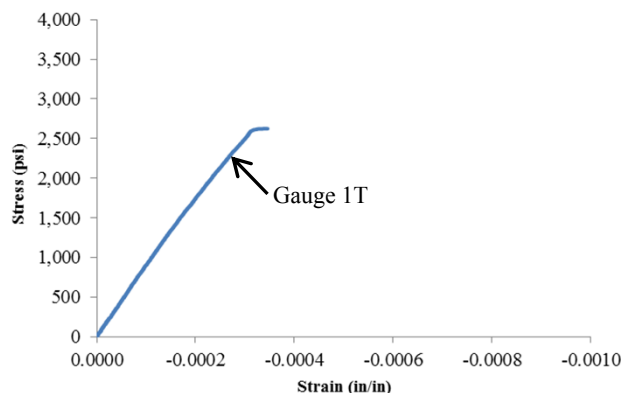
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001115 | 0.000429 | 1T | -0.000147 | -0.000058 | 0.1294 |
| 2L | Lost | Gauge | 2T | Lost | Gauge | - |
| Average | | | | | | 0.1294 |

Stress-Strain Curve_70°F_1_(09-01)_Long



Stress-Strain Curve_70°F_1_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-70-FY09**
 Test Date: 9/22/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 2,806 lbs
 Poisson's Ratio, v_{xz} : 0.1609

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.001 in
 Side 2: 1.001 in

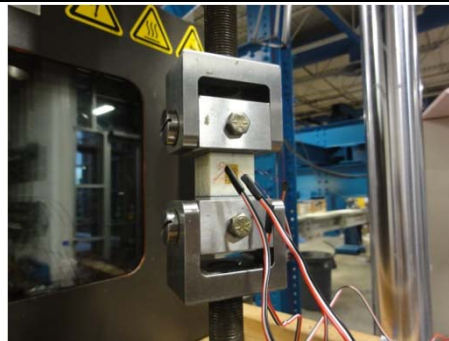
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,403 lbs

20% Max Load: 561 lbs

PICTURE OF SPECIMEN PRE-TEST



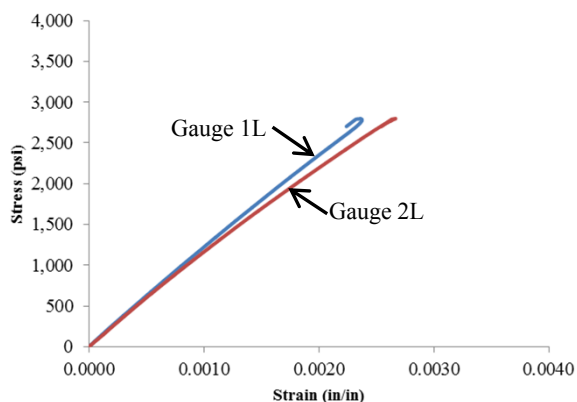
PICTURE OF SPECIMEN POST-TEST



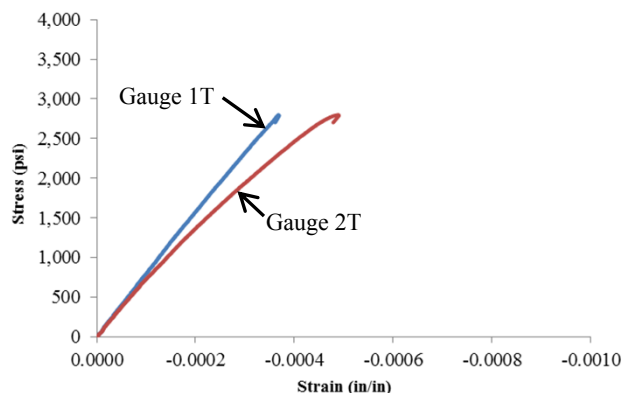
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001152 | 0.000445 | 1T | -0.000176 | -0.000070 | 0.1504 |
| 2L | 0.001219 | 0.000464 | 2T | -0.000205 | -0.000076 | 0.1715 |
| Average | | | | | | 0.1609 |

Stress-Strain Curve_70°F_2_(09-01)_Long



Stress-Strain Curve_70°F_2_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-70-FY09**
 Test Date: 9/22/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

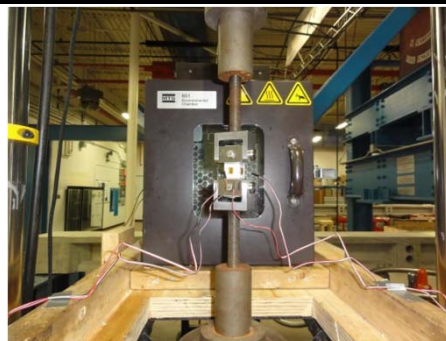
Maximum Load, P_z : 2,395 lbs
 Poisson's Ratio, v_{xz} : 0.1390

Measured Specimen Dimensions:

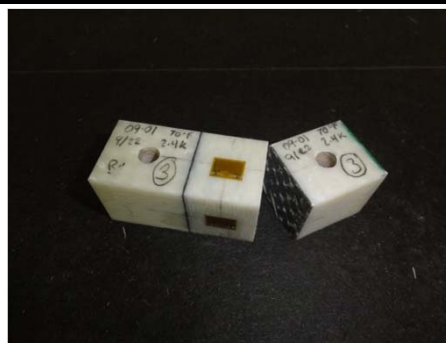
Thickness: 1.000 in
 Side 1: 1.001 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,198 lbs
 20% Max Load: 479 lbs

PICTURE OF SPECIMEN PRE-TEST



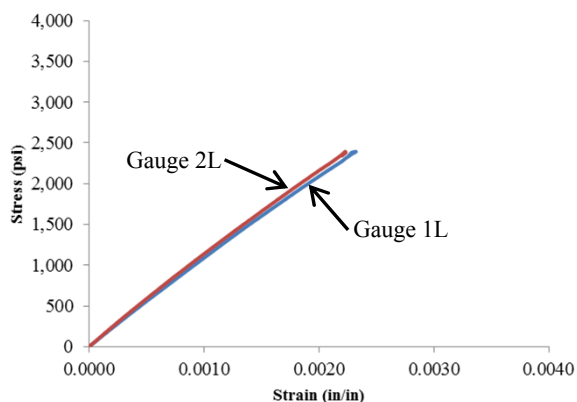
PICTURE OF SPECIMEN POST-TEST



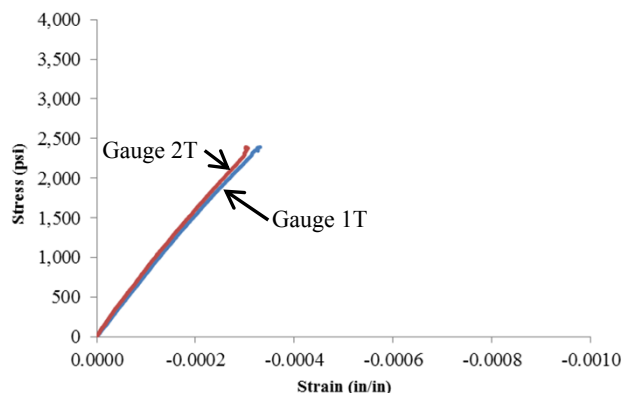
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001102 | 0.000428 | 1T | -0.000153 | -0.000060 | 0.1385 |
| 2L | 0.001055 | 0.000404 | 2T | -0.000144 | -0.000053 | 0.1394 |
| Average | | | | | | 0.1390 |

Stress-Strain Curve_70°F_3_(09-01)_Long



Stress-Strain Curve_70°F_3_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-70-FY09**
 Test Date: 9/22/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 2,413 lbs
 Poisson's Ratio, v_{xz} : 0.1432

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.001 in
 Side 2: 1.000 in

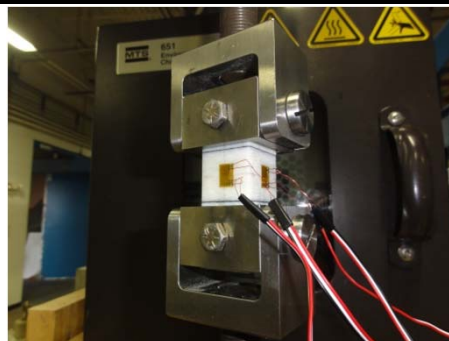
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,207 lbs

20% Max Load: 483 lbs

PICTURE OF SPECIMEN PRE-TEST



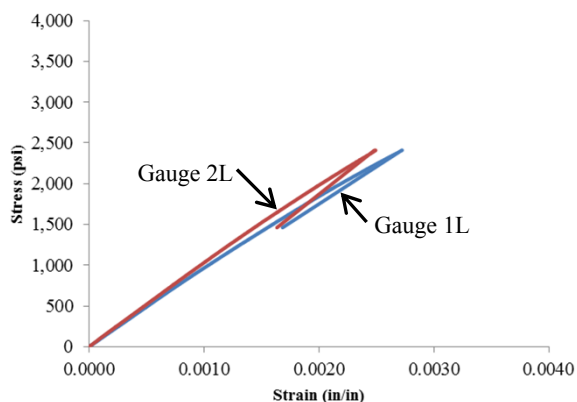
PICTURE OF SPECIMEN POST-TEST



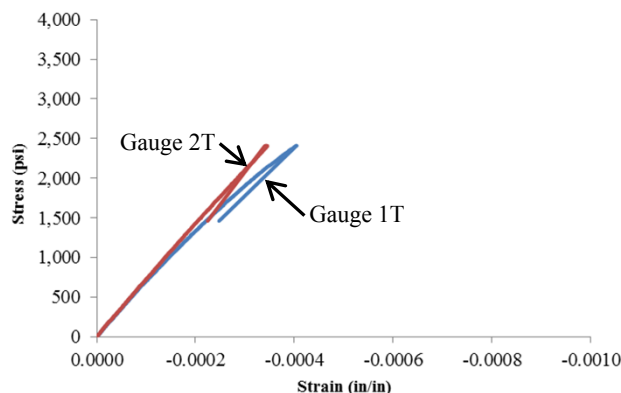
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001264 | 0.000493 | 1T | -0.000178 | -0.000068 | 0.1437 |
| 2L | 0.001174 | 0.000464 | 2T | -0.000167 | -0.000066 | 0.1427 |
| Average | | | | | | 0.1432 |

Stress-Strain Curve_70°F_4_(09-01)_Long



Stress-Strain Curve_70°F_4_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-70-FY09**
 Test Date: 9/22/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

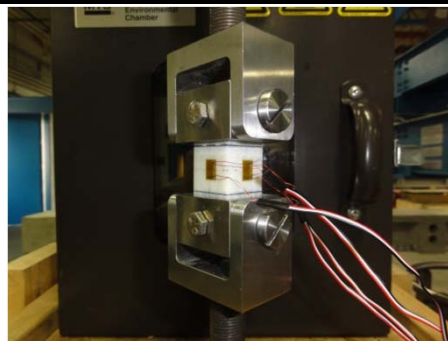
Maximum Load, P_z : 3,007 lbs
 Poisson's Ratio, v_{xz} : 0.1101

Measured Specimen Dimensions:

Thickness: 1.000 in
 Side 1: 1.000 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,503 lbs
 20% Max Load: 601 lbs

PICTURE OF SPECIMEN PRE-TEST



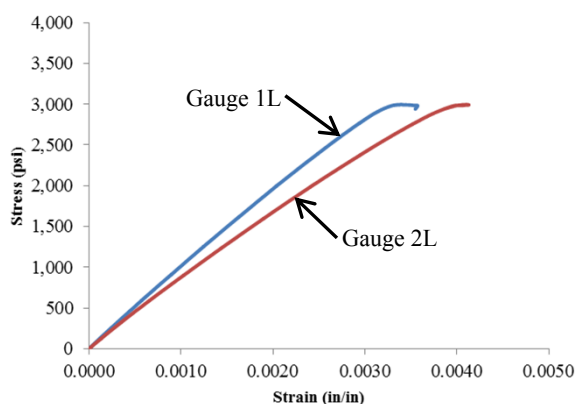
PICTURE OF SPECIMEN POST-TEST



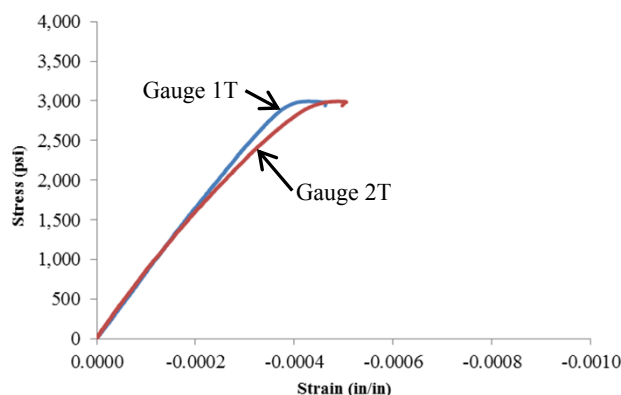
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001503 | 0.000577 | 1T | -0.000180 | -0.000073 | 0.1158 |
| 2L | 0.001772 | 0.000665 | 2T | -0.000184 | -0.000069 | 0.1045 |
| Average | | | | | | 0.1101 |

Stress-Strain Curve_70°F_5_(09-01)_Long



Stress-Strain Curve_70°F_5_(09-01)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

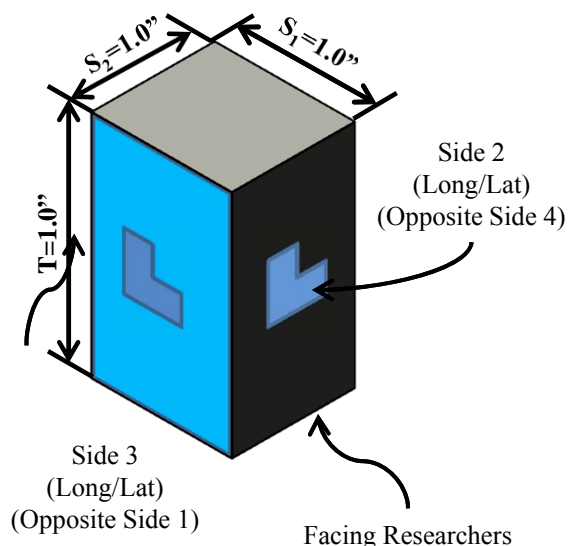
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT1-OP-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1182
 Maximum Load, P_z : 1,860 lbs

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|----------------------|-----------------------------|--------------|
| 1 | MAT1-OP-1-140-FY09 | 1,874 | 0.0674 | Bondline |
| 2 | MAT1-OP-2-140-FY09 | 1,840 | 0.1161 | Rupture |
| 3 | MAT1-OP-3-140-FY09 | 1,868 | 0.1592 | Rupture |
| 4 | MAT1-OP-4-140-FY09 | 1,846 | 0.1384 | Rupture |
| 5 | MAT1-OP-5-140-FY09 | 1,872 | 0.1098 | Rupture |
| Average | | 1,860 | 0.1182 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Test ConditionNominal Dimensions/
Strain Gauge Configuration**Notes:**

- 1) Reference D-122 thru D-126 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-1-140-FY09**
 Test Date: 05/17/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,874 lbs
 Poisson's Ratio, v_{xz} : 0.0674

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.991 in

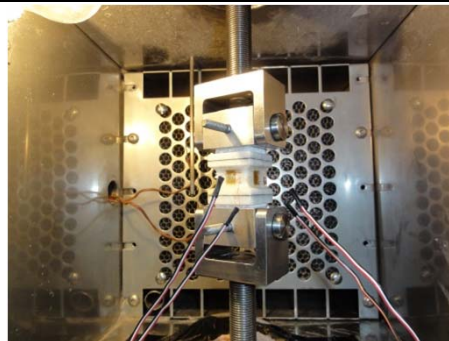
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 937 lbs

20% Max Load: 375 lbs

PICTURE OF SPECIMEN PRE-TEST



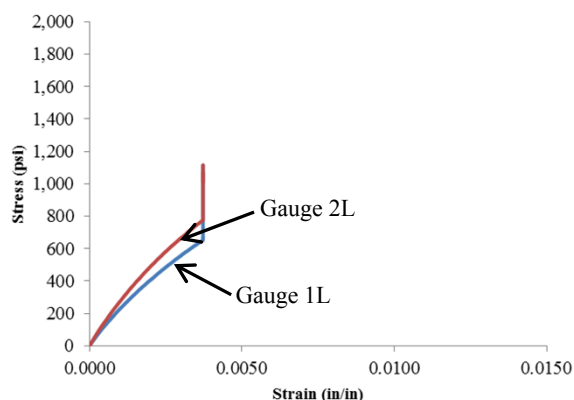
PICTURE OF SPECIMEN POST-TEST



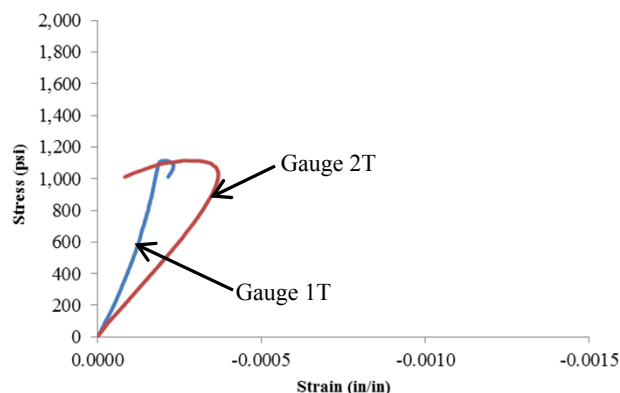
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003720 | 0.001851 | 1T | -0.000172 | -0.000088 | 0.0449 |
| 2L | 0.003720 | 0.001474 | 2T | -0.000361 | -0.000159 | 0.0898 |
| Average | | | | | | 0.0674 |

Stress-Strain Curve_140_1_(09-01)_Long



Stress-Strain Curve_140_1_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT1-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-2-140-FY09**
 Test Date: 05/18/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,840 lbs
 Poisson's Ratio, v_{xz} : 0.1161

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.988 in
 Side 2: 0.984 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 920 lbs

20% Max Load: 368 lbs

PICTURE OF SPECIMEN PRE-TEST



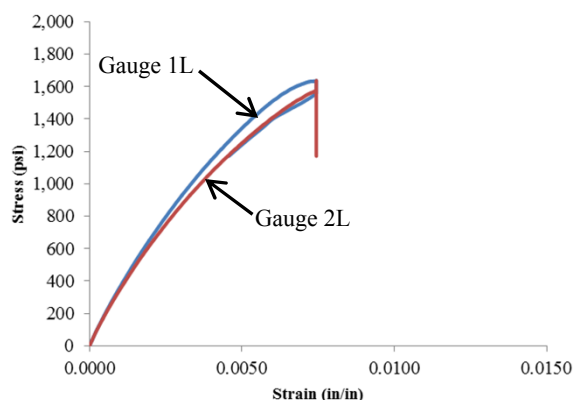
PICTURE OF SPECIMEN POST-TEST



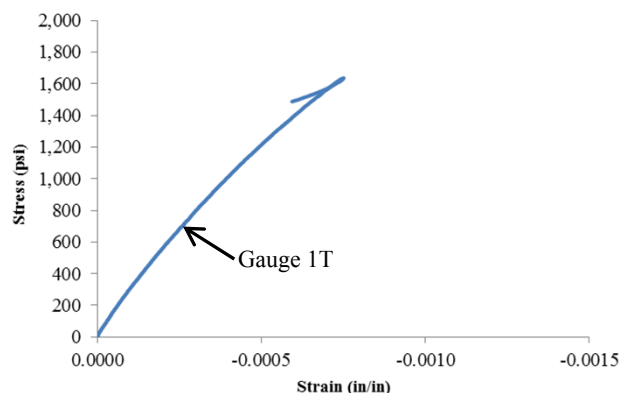
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003221 | 0.001076 | 1T | -0.000381 | -0.000132 | 0.1161 |
| 2L | 0.003510 | 0.001137 | 2T | LOST GAUGE | | |
| Average | | | | | | 0.1161 |

Stress-Strain Curve_140_2_(09-01)_Long



Stress-Strain Curve_140_2_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT1-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-3-140-FY09**
 Test Date: 05/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,868 lbs
 Poisson's Ratio, v_{xz} : 0.1592

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.989 in

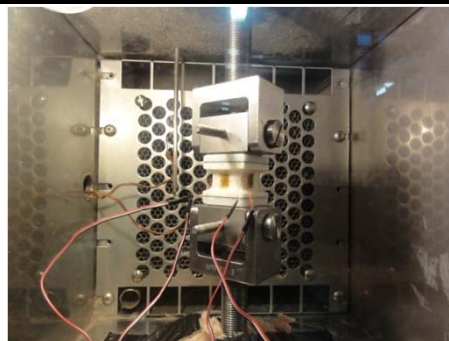
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 934 lbs

20% Max Load: 374 lbs

PICTURE OF SPECIMEN PRE-TEST



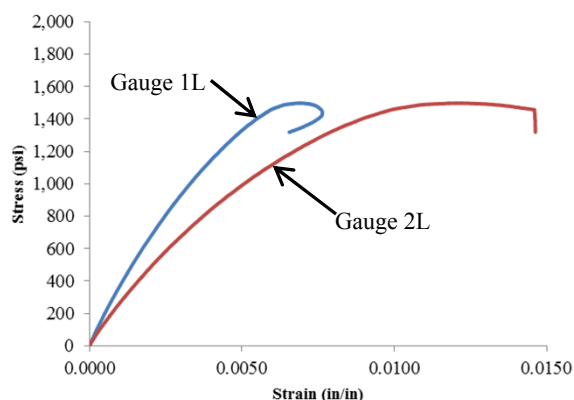
PICTURE OF SPECIMEN POST-TEST



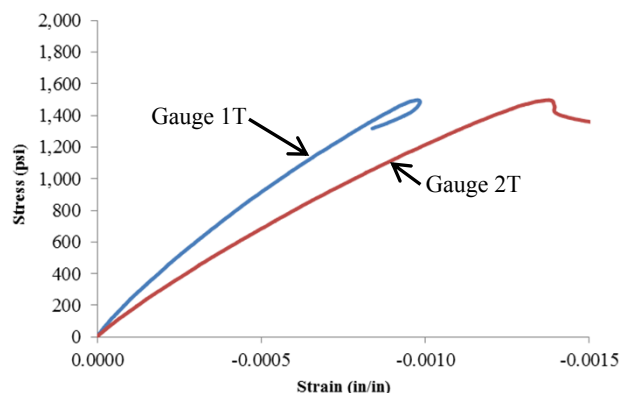
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003119 | 0.001035 | 1T | -0.000530 | -0.000178 | 0.1691 |
| 2L | 0.004779 | 0.001521 | 2T | -0.000745 | -0.000258 | 0.1493 |
| Average | | | | | | 0.1592 |

Stress-Strain Curve_140_3_(09-01)_Long



Stress-Strain Curve_140_3_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT1-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-4-140-FY09**
 Test Date: 05/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,846 lbs
 Poisson's Ratio, v_{xz} : 0.1384

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.989 in
 Side 2: 0.986 in

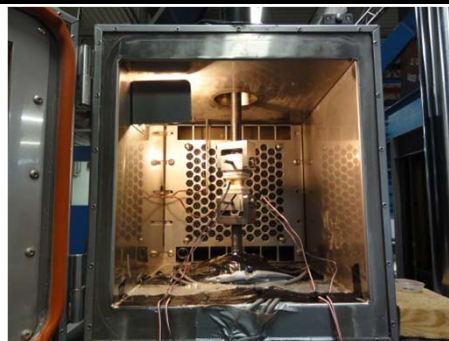
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 923 lbs

20% Max Load: 369 lbs

PICTURE OF SPECIMEN PRE-TEST



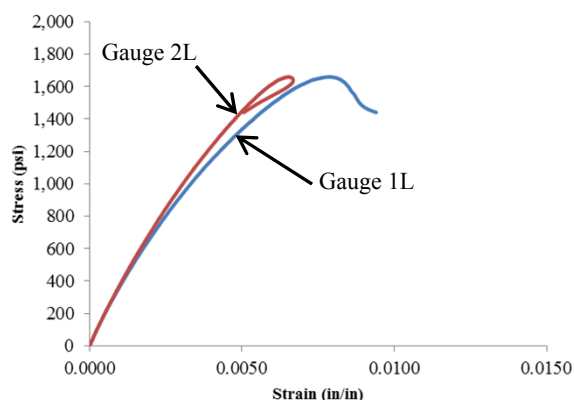
PICTURE OF SPECIMEN POST-TEST



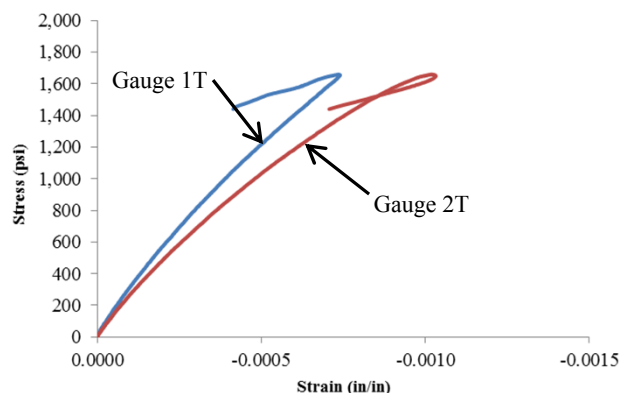
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003196 | 0.001060 | 1T | -0.000376 | -0.000127 | 0.1164 |
| 2L | 0.002951 | 0.001024 | 2T | -0.000463 | -0.000154 | 0.1604 |
| Average | | | | | | 0.1384 |

Stress-Strain Curve_140_4_(09-01)_Long



Stress-Strain Curve_140_4_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT1-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT1-OP-5-140-FY09**
 Test Date: 05/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,872 lbs
 Poisson's Ratio, v_{xz} : 0.1098

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.996 in
 Side 2: 0.993 in

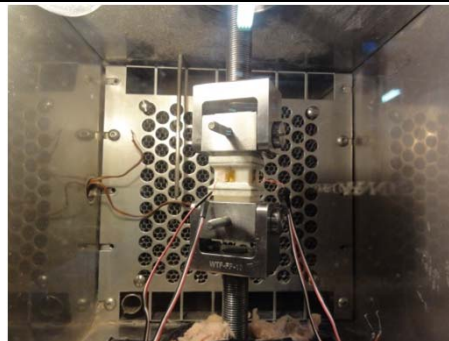
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 936 lbs

20% Max Load: 374 lbs

PICTURE OF SPECIMEN PRE-TEST



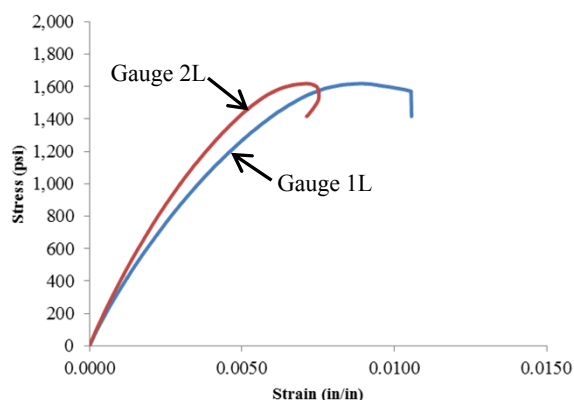
PICTURE OF SPECIMEN POST-TEST



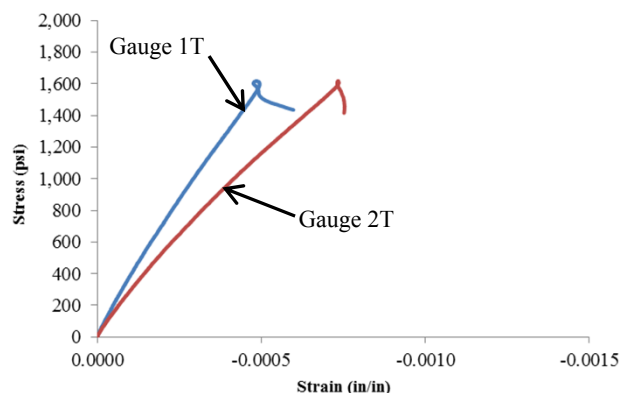
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003371 | 0.001110 | 1T | -0.000279 | -0.000099 | 0.0797 |
| 2L | 0.002814 | 0.000955 | 2T | -0.000396 | -0.000136 | 0.1399 |
| Average | | | | | | 0.1098 |

Stress-Strain Curve_140_5_(09-01)_Long



Stress-Strain Curve_140_5_(09-01)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT1-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX E

MATERIAL 2-FY09 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-TX-N40-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **-40°F**
 Properties Measured: **ST_x , E_x , ν_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : **16,585** **lbs**
 Tensile Strength, ST_x : **45,714** **psi**
 Tensile Modulus, E_x : **2,100,891** **psi**
 Ultimate Strain, ϵ_x : **0.0218** **in/in**
 Poisson's Ratio, ν_{xy} : **0.2159**

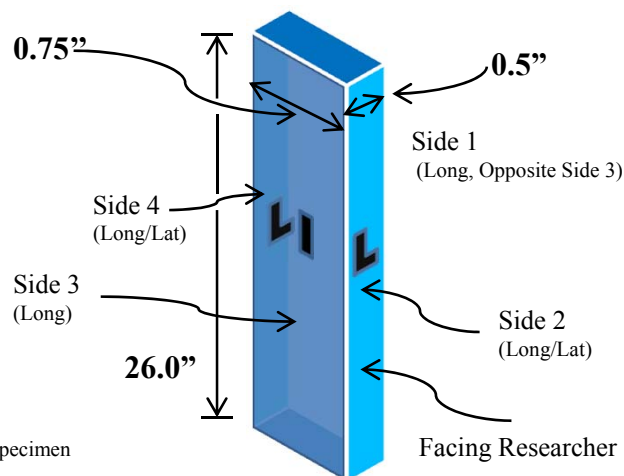
| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT2-TX-1-N40-FY09 | 16,068 | 44,616 | 2,151,804 | 0.0207 | 0.2172 | DGM |
| 2 | MAT2-TX-2-N40-FY09 | 15,544 | 44,561 | 2,135,854 | 0.0209 | 0.2063 | DGM |
| 3 | MAT2-TX-3-N40-FY09 | 16,408 | 45,830 | 2,081,038 | 0.0220 | 0.2228 | DGM |
| 4 | MAT2-TX-4-N40-FY09 | 17,038 | 46,947 | 2,029,061 | 0.0231 | 0.2022 | DGM |
| 5 | MAT2-TX-5-N40-FY09 | 17,867 | 46,615 | 2,106,699 | 0.0221 | 0.2308 | DGM |
| Average | | 16,585 | 45,714 | 2,100,891 | 0.0218 | 0.2159 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See E-2 to E-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-N40-FY09**
 Test Date: 7/11/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,068 lbs
 Tensile Strength, ST_x : 44,616 psi
 Tensile Modulus, E_x : 2,151,804 psi
 Ultimate Strain, ϵ_x : 0.0207 in/in
 Poisson's Ratio, v_{xy} : 0.2172

Measured Specimen Dimensions:

Width, W: 0.4814 in
 Thickness, H: 0.7481 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,214 lbs
 50% Max Load: 8,034 lbs

PICTURE OF SPECIMEN PRE-TEST



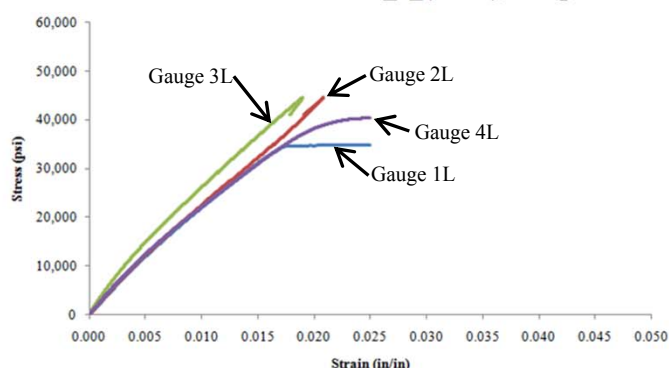
PICTURE OF SPECIMEN POST-TEST



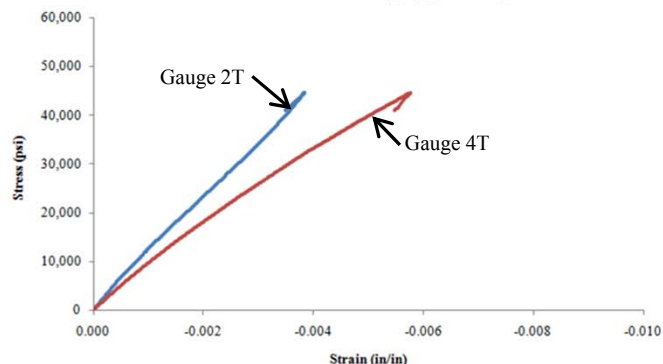
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0102 | 0.0037 | 2,053,619 | | | | |
| 2L | 0.0099 | 0.0036 | 2,114,921 | 2T | -0.0019 | -0.0007 | 0.1927 |
| 3L | 0.0082 | 0.0027 | 2,434,220 | | | | |
| 4L | 0.0101 | 0.0034 | 2,004,457 | 4T | -0.0025 | -0.0009 | 0.2418 |
| Average | | | 2,151,804 | | | | 0.2172 |

Stress-Strain Curve -40°F_1_(09-02), Long.



Stress-Strain Curve -40°F_1_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-N40-FY09**
 Test Date: 7/13/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

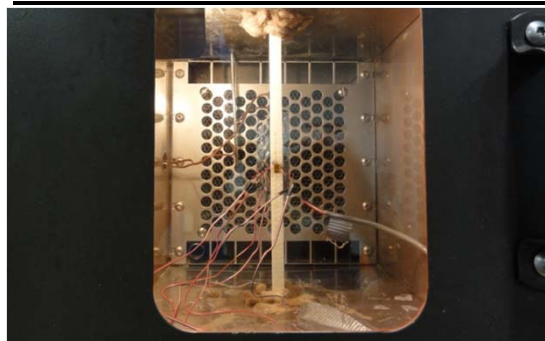
Average Material Properties:

Ultimate Load, P_x : 15,544 lbs
 Tensile Strength, ST_x : 44,561 psi
 Tensile Modulus, E_x : 2,135,854 psi
 Ultimate Strain, ϵ_x : 0.0209 in/in
 Poisson's Ratio, ν_{xy} : 0.2063

Measured Specimen Dimensions:

Width, W : 0.4640 in
 Thickness, H : 0.7518 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,109 lbs
 50% Max Load: 7,772 lbs

PICTURE OF SPECIMEN PRE-TEST



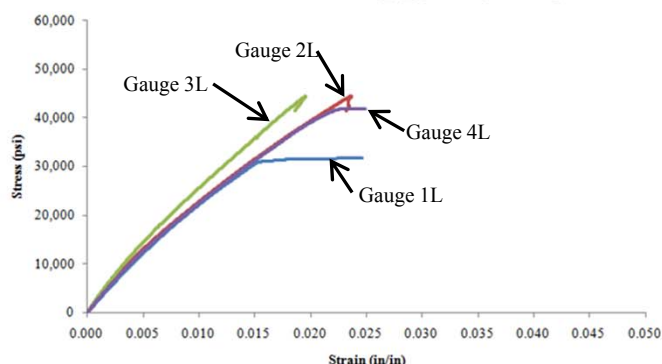
PICTURE OF SPECIMEN POST-TEST



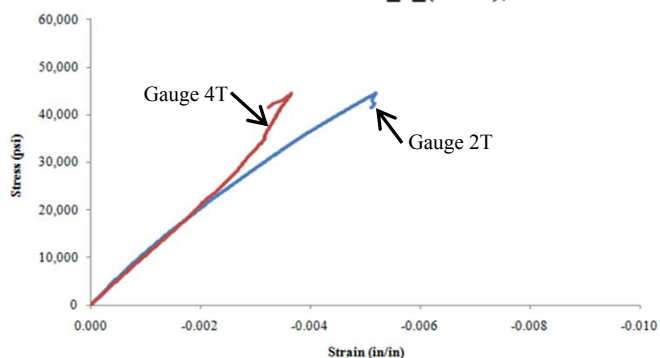
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0101 | 0.0036 | 2,052,218 | | | | |
| 2L | 0.0097 | 0.0032 | 2,050,503 | 2T | -0.0022 | -0.0008 | 0.2188 |
| 3L | 0.0085 | 0.0029 | 2,392,475 | | | | |
| 4L | 0.0099 | 0.0034 | 2,048,220 | 4T | -0.0021 | -0.0008 | 0.1939 |
| Average | | | 2,135,854 | | | | 0.2063 |

Stress-Strain Curve -40°F_2_(09-02), Long.



Stress-Strain Curve -40°F_2_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-N40-FY09**
 Test Date: 7/13/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_x , E_x , ν_{xy}

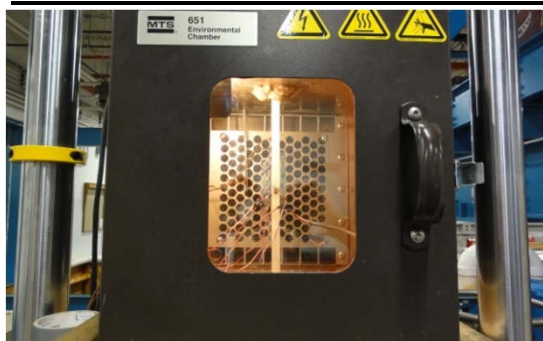
Average Material Properties:

Ultimate Load, P_x : 16,408 lbs
 Tensile Strength, ST_x : 45,830 psi
 Tensile Modulus, E_x : 2,081,038 psi
 Ultimate Strain, ϵ_x : 0.0220 in/in
 Poisson's Ratio, ν_{xy} : 0.2228

Measured Specimen Dimensions:

Width, W: 0.4818 in
 Thickness, H: 0.7431 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,282 lbs
 50% Max Load: 8,204 lbs

PICTURE OF SPECIMEN PRE-TEST



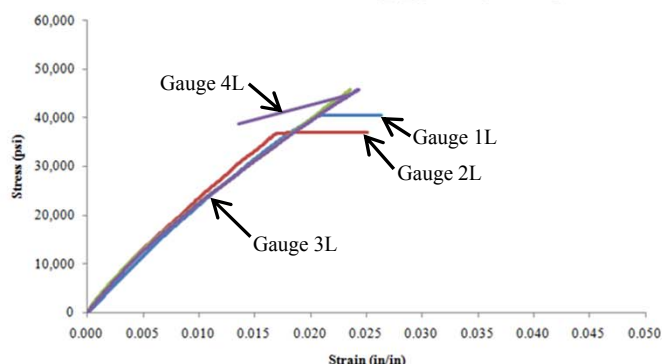
PICTURE OF SPECIMEN POST-TEST



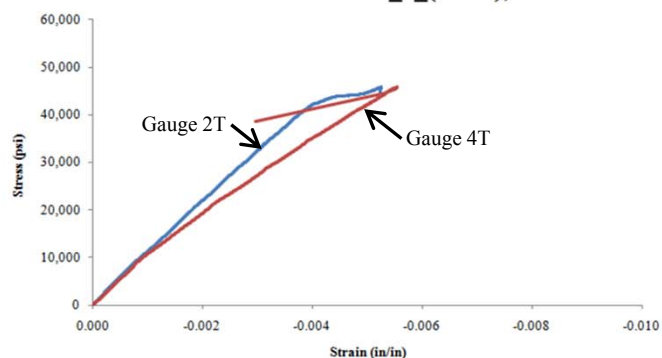
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0104 | 0.0039 | 2,119,550 | | | | |
| 2L | 0.0097 | 0.0034 | 2,181,243 | 2T | -0.0021 | -0.0008 | 0.2086 |
| 3L | 0.0102 | 0.0033 | 1,988,157 | 3T | -0.0032 | -0.0011 | 0.3095 |
| 4L | 0.0103 | 0.0035 | 2,035,201 | 4T | -0.0024 | -0.0008 | 0.2369 |
| Average | | | 2,081,038 | | | | 0.2228 |

Stress-Strain Curve -40°F_3_(09-02), Long.



Stress-Strain Curve -40°F_3_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-N40-FY09**
 Test Date: 7/13/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 17,038 lbs
 Tensile Strength, ST_x : 46,947 psi
 Tensile Modulus, E_x : 2,029,061 psi
 Ultimate Strain, ϵ_x : 0.0231 in/in
 Poisson's Ratio, v_{xy} : 0.2022

Measured Specimen Dimensions:

Width, W : 0.4937 in
 Thickness, H : 0.7351 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,408 lbs
 50% Max Load: 8,519 lbs

PICTURE OF SPECIMEN PRE-TEST



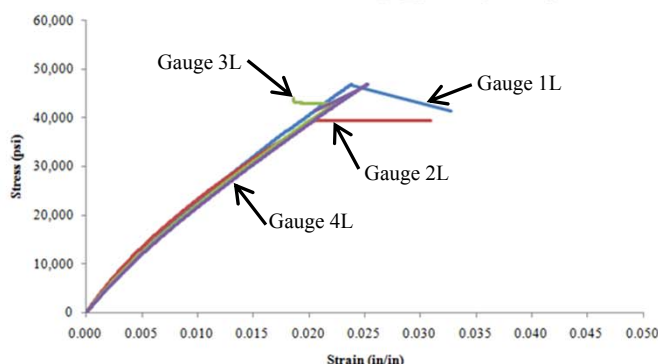
PICTURE OF SPECIMEN POST-TEST



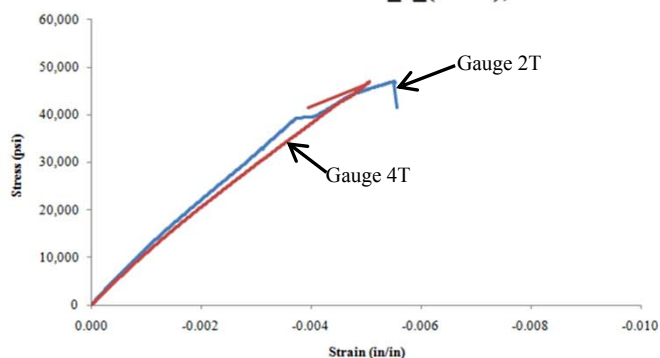
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0104 | 0.0037 | 2,102,885 | | | | |
| 2L | 0.0101 | 0.0033 | 2,064,804 | 2T | -0.0021 | -0.0008 | 0.2002 |
| 3L | 0.0107 | 0.0037 | 1,992,122 | | | | |
| 4L | 0.0110 | 0.0038 | 1,956,431 | 4T | -0.0023 | -0.0008 | 0.2041 |
| Average | | | 2,029,061 | | | | 0.2022 |

Stress-Strain Curve -40°F_4_(09-02), Long.



Stress-Strain Curve -40°F_4_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-N40-FY09**
 Test Date: 7/14/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , v_{xy}

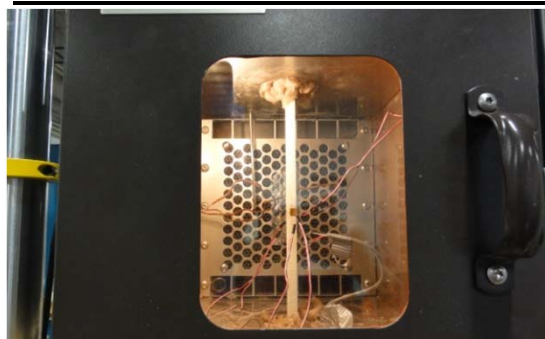
Average Material Properties:

Ultimate Load, P_x : 17,867 lbs
 Tensile Strength, ST_x : 46,615 psi
 Tensile Modulus, E_x : 2,106,699 psi
 Ultimate Strain, ϵ_x : 0.0221 in/in
 Poisson's Ratio, v_{xy} : 0.2308

Measured Specimen Dimensions:

Width, W: 0.5050 in
 Thickness, H: 0.7590 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,573 lbs
 50% Max Load: 8,934 lbs

PICTURE OF SPECIMEN PRE-TEST



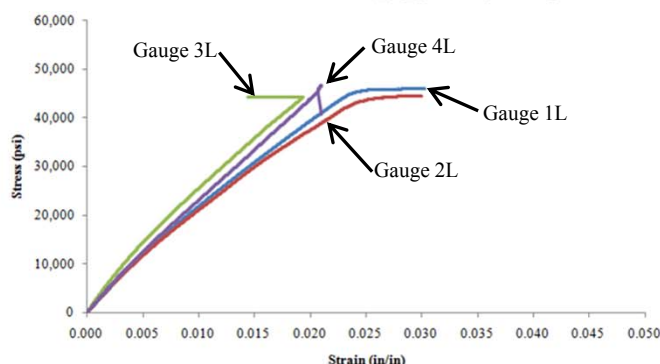
PICTURE OF SPECIMEN POST-TEST



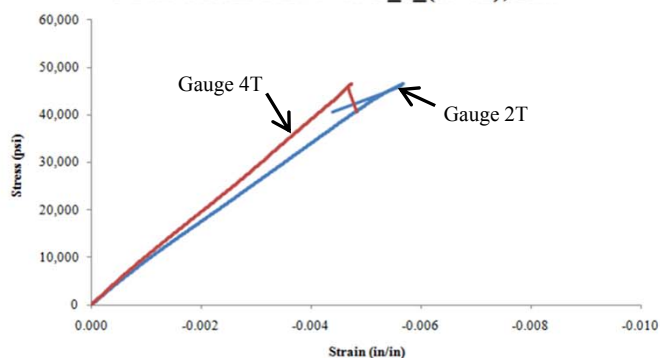
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0108 | 0.0038 | 2,011,082 | | | | |
| 2L | 0.0113 | 0.0039 | 1,891,040 | 2T | -0.0027 | -0.0010 | 0.2302 |
| 3L | 0.0089 | 0.0030 | 2,365,833 | | | | |
| 4L | 0.0101 | 0.0036 | 2,158,840 | 4T | -0.0024 | -0.0009 | 0.2314 |
| Average | | | 2,106,699 | | | | 0.2308 |

Stress-Strain Curve -40°F_5_(09-02), Long.



Stress-Strain Curve -40°F_5_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TX-70-FY09
Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
Nominal Temperature: 70°F
Properties Measured: ST_x , E_x , ν_{xy}
Average Material Properties (5 Specimens):
Ultimate Load, P_x : 16,197 lbs
Tensile Strength, ST_x : 43,257 psi
Tensile Modulus, E_x : 1,784,110 psi
Ultimate Strain, ϵ_x : 0.0243 in/in
Poisson's Ratio, ν_{xy} : 0.2477

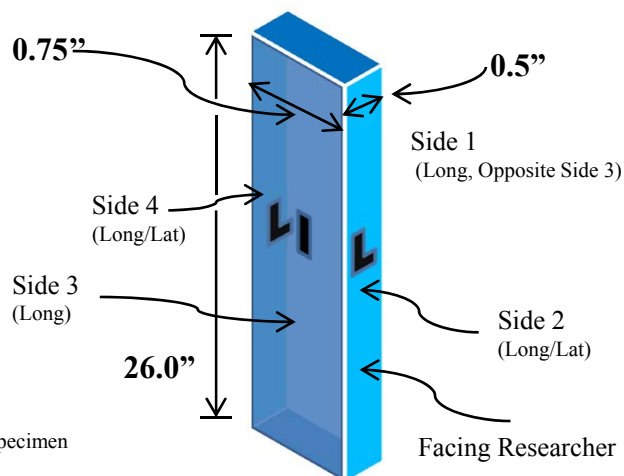
| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|-------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT2-TX-70-FY09-1 | 16,135 | 43,708 | 1,661,922 | 0.0263 | 0.2484 | DGM |
| 2 | MAT2-TX-70-FY09-2 | 16,379 | 43,680 | 1,762,456 | 0.0248 | 0.2436 | DGM |
| 3 | MAT2-TX-70-FY09-3 | 16,281 | 42,562 | 1,912,545 | 0.0223 | 0.1944 | DGM |
| 4 | MAT2-TX-70-FY09-4 | 16,358 | 43,392 | 1,776,659 | 0.0244 | 0.2712 | DGM |
| 5 | MAT2-TX-70-FY09-5 | 15,831 | 42,941 | 1,806,969 | 0.0238 | 0.2807 | DGM |
| Average | | 16,197 | 43,257 | 1,784,110 | 0.0243 | 0.2477 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint is used to eliminate all moments about the fixed lower head and allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) 10 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See E-8 to E-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-70-FY09**
 Test Date: 6/08/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

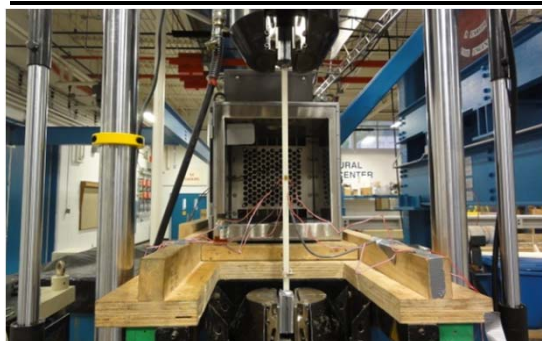
Average Material Properties:

Ultimate Load, P_x : 16,135 lbs
 Tensile Strength, ST_x : 43,708 psi
 Tensile Modulus, E_x : 1,661,922 psi
 Ultimate Strain, ϵ_x : 0.0263 in/in
 Poisson's Ratio, ν_{xy} : 0.2484

Measured Specimen Dimensions:

Width, W: 0.4883 in
 Thickness, H: 0.7560 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,227 lbs
 50% Max Load: 8,067 lbs

PICTURE OF SPECIMEN PRE-TEST



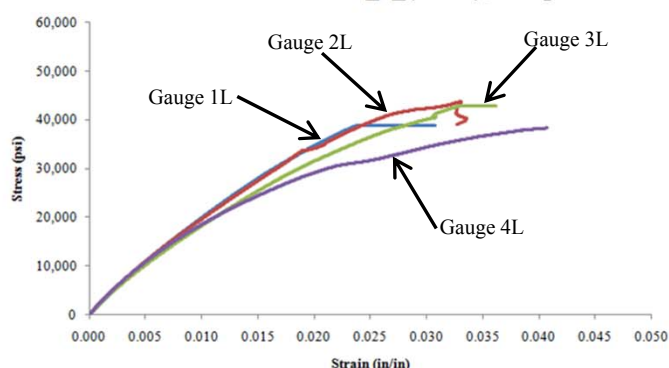
PICTURE OF SPECIMEN POST-TEST



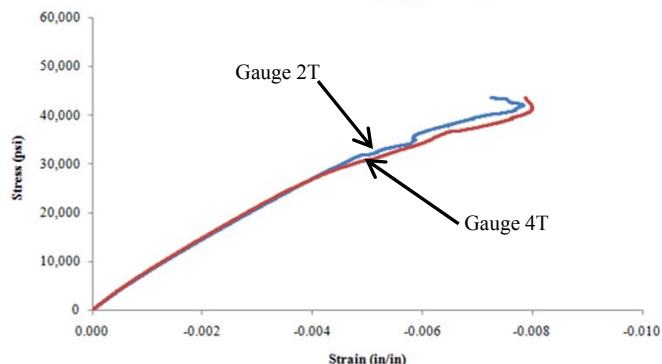
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0111 | 0.0040 | 1,823,271 | | | | |
| 2L | 0.0114 | 0.0039 | 1,749,474 | 2T | -0.0032 | -0.0011 | 0.2698 |
| 3L | 0.0125 | 0.0042 | 1,585,400 | | | | |
| 4L | 0.0127 | 0.0039 | 1,489,544 | 4T | -0.0031 | -0.0011 | 0.2269 |
| Average | | | 1,661,922 | | | | 0.2484 |

Stress-Strain Curve 70_1_(09-02), Long.



Stress-Strain Curve 70_1_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-70-FY09**
 Test Date: 6/08/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,379 lbs
 Tensile Strength, ST_x : 43,680 psi
 Tensile Modulus, E_x : 1,762,456 psi
 Ultimate Strain, ϵ_x : 0.0248 in/in
 Poisson's Ratio, v_{xy} : 0.2436

Measured Specimen Dimensions:

Width, W: 0.4960 in
 Thickness, H: 0.7560 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,276 lbs
 50% Max Load: 8,190 lbs

PICTURE OF SPECIMEN PRE-TEST



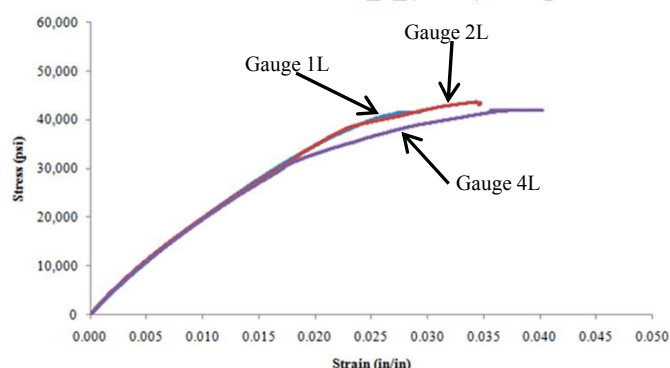
PICTURE OF SPECIMEN POST-TEST



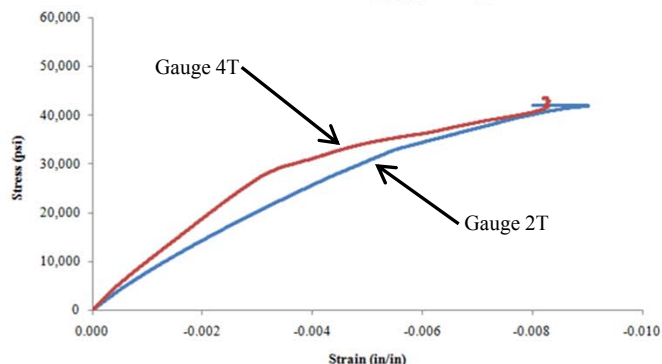
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0112 | 0.0040 | 1,806,173 | | | | |
| 2L | 0.0113 | 0.0038 | 1,745,006 | 2T | -0.0033 | -0.0011 | 0.2877 |
| 3L | Lost Gauge | | | | | | |
| 4L | 0.0114 | 0.0039 | 1,736,187 | 4T | -0.0024 | -0.0009 | 0.1994 |
| Average | | | 1,762,456 | | | | 0.2436 |

Stress-Strain Curve 70_2_(09-02), Long.



Stress-Strain Curve 70_2_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-70-FY09**
 Test Date: 6/09/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

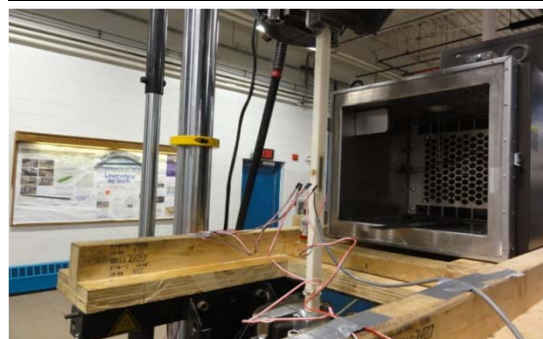
Average Material Properties:

Ultimate Load, P_x : 16,281 lbs
 Tensile Strength, ST_x : 42,562 psi
 Tensile Modulus, E_x : 1,912,545 psi
 Ultimate Strain, ϵ_x : 0.0223 in/in
 Poisson's Ratio, ν_{xy} : 0.1944

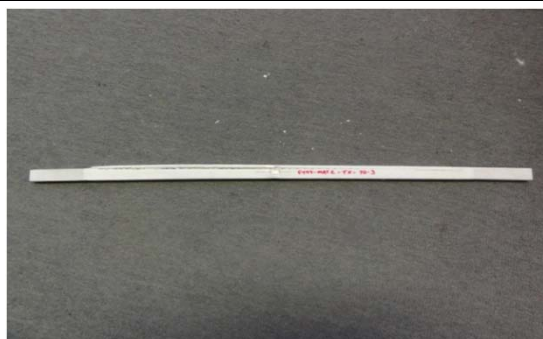
Measured Specimen Dimensions:

Width, W: 0.5040 in
 Thickness, H: 0.7590 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,256 lbs
 50% Max Load: 8,141 lbs

PICTURE OF SPECIMEN PRE-TEST



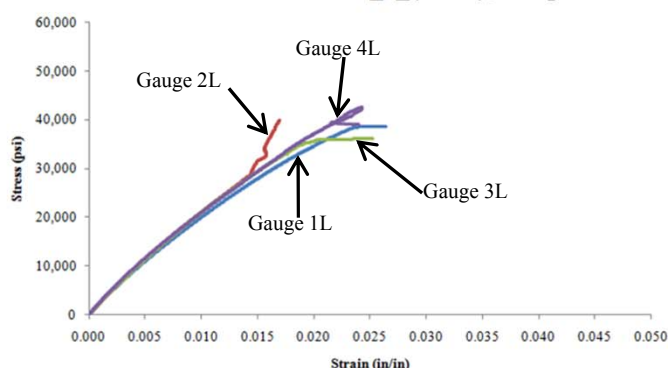
PICTURE OF SPECIMEN POST-TEST



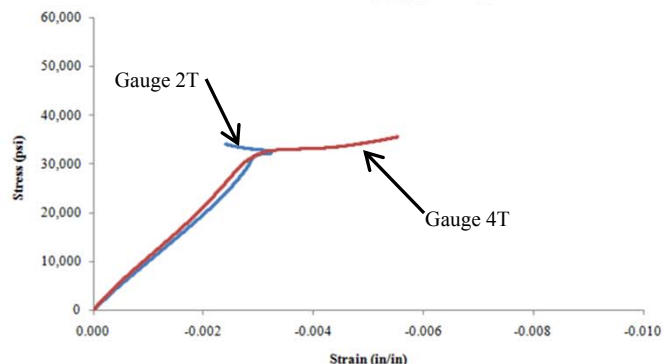
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0108 | 0.0038 | 1,823,374 | | | | |
| 2L | 0.0101 | 0.0036 | 1,949,821 | 2T | -0.0022 | -0.0008 | 0.2011 |
| 3L | 0.0102 | 0.0037 | 1,959,606 | | | | |
| 4L | 0.0102 | 0.0035 | 1,917,378 | 4T | -0.0020 | -0.0008 | 0.1877 |
| Average | | | 1,912,545 | | | | 0.1944 |

Stress-Strain Curve 70_3_(09-02), Long.



Stress-Strain Curve 70_3_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-70-FY09**
 Test Date: 6/09/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,358 lbs
 Tensile Strength, ST_x : 43,392 psi
 Tensile Modulus, E_x : 1,776,659 psi
 Ultimate Strain, ϵ_x : 0.0244 in/in
 Poisson's Ratio, ν_{xy} : 0.2712

Measured Specimen Dimensions:

Width, W : 0.4980 in
 Thickness, H : 0.7570 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,272 lbs
 50% Max Load: 8,179 lbs

PICTURE OF SPECIMEN PRE-TEST



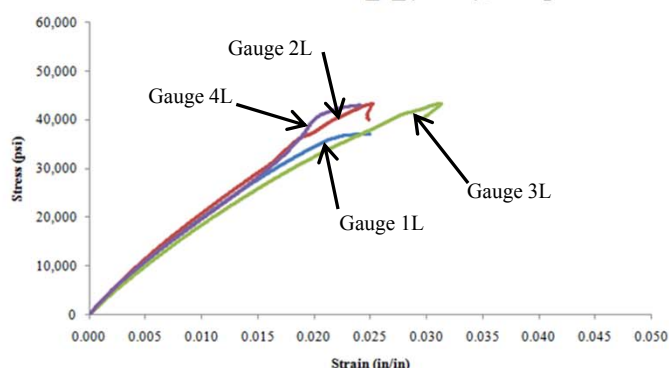
PICTURE OF SPECIMEN POST-TEST



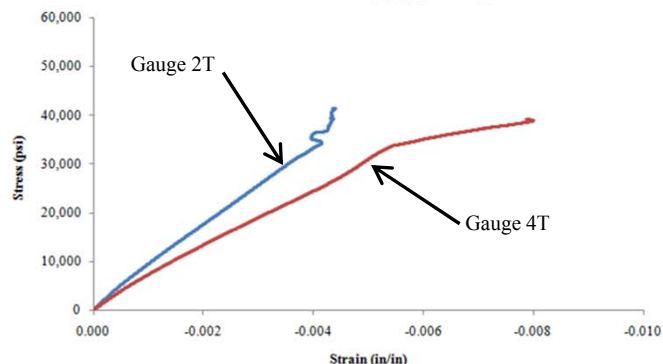
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0111 | 0.0039 | 1,795,146 | | | | |
| 2L | 0.0105 | 0.0037 | 1,896,829 | 2T | -0.0025 | -0.0009 | 0.2352 |
| 3L | 0.0121 | 0.0043 | 1,664,241 | | | | |
| 4L | 0.0112 | 0.0038 | 1,750,420 | 4T | -0.0035 | -0.0012 | 0.3073 |
| Average | | | 1,776,659 | | | | 0.2712 |

Stress-Strain Curve 70_4_(09-02), Long.



Stress-Strain Curve 70_4_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-70-FY09**
 Test Date: 6/09/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

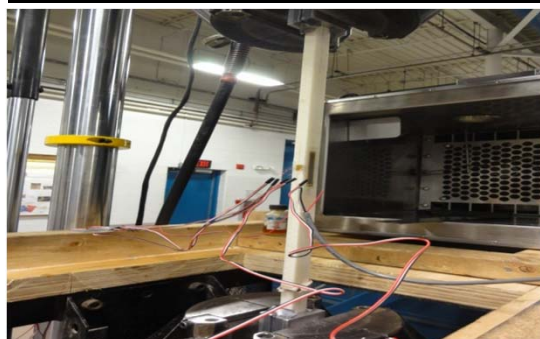
Average Material Properties:

Ultimate Load, P_x : 15,831 lbs
 Tensile Strength, ST_x : 42,941 psi
 Tensile Modulus, E_x : 1,806,969 psi
 Ultimate Strain, ϵ_x : 0.0238 in/in
 Poisson's Ratio, ν_{xy} : 0.2807

Measured Specimen Dimensions:

Width, W: 0.4870 in
 Thickness, H: 0.7570 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,166 lbs
 50% Max Load: 7,915 lbs

PICTURE OF SPECIMEN PRE-TEST



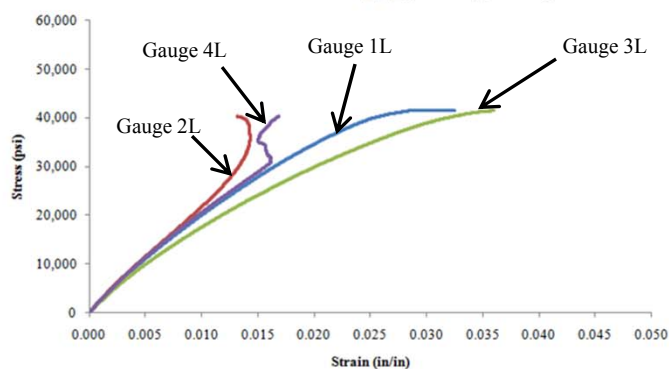
PICTURE OF SPECIMEN POST-TEST



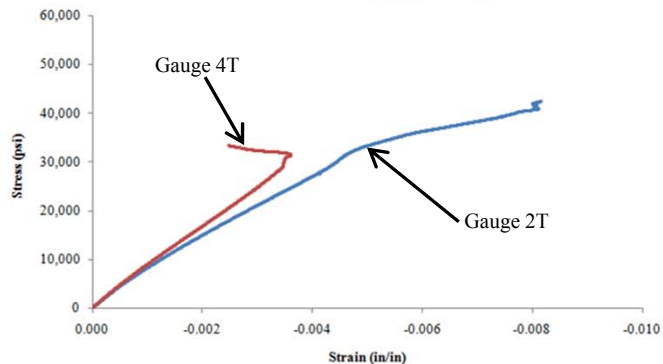
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0109 | 0.0038 | 1,811,885 | | | | |
| 2L | 0.0099 | 0.0036 | 2,049,037 | 2T | -0.0031 | -0.0010 | 0.3212 |
| 3L | 0.0129 | 0.0042 | 1,487,357 | | | | |
| 4L | 0.0105 | 0.0037 | 1,879,596 | 4T | -0.0026 | -0.0010 | 0.2402 |
| Average | | | 1,806,969 | | | | 0.2807 |

Stress-Strain Curve 70_5_(09-02), Long.



Stress-Strain Curve 70_5_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-TX-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **ST_x, E_x, v_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **11,021** **lbs**
 Tensile Strength, ST_x: **30,979** **psi**
 Tensile Modulus, E_x: **1,663,892** **psi**
 Ultimate Strain, ε_x: **0.0189** **in/in**
 Poisson's Ratio, v_{xy}: **0.4277**

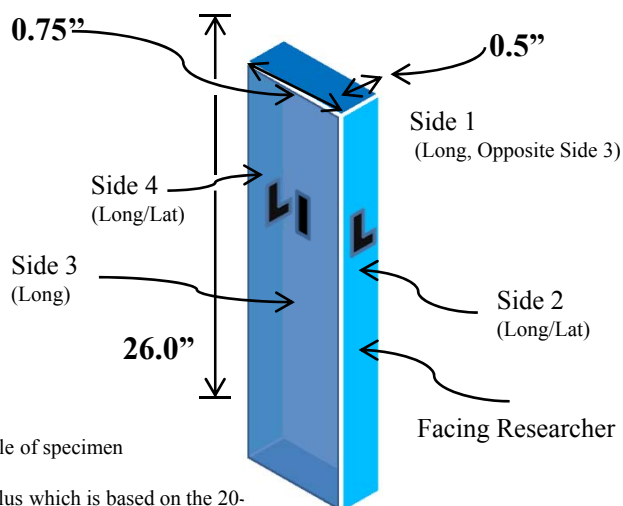
| Sample | Specimen | Max Load, P _x (lbs) | Tensile Strength, ST _x (psi) | Tensile Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, v _{xy} | Failure Mode |
|----------------|--------------------|-----------------------------------|---|--|--|----------------------------------|--------------|
| 1 | MAT2-TX-140-FY09-1 | 12,936 | 34,006 | 1,277,320 | 0.0266 | 0.3853 | DGM |
| 2 | MAT2-TX-140-FY09-2 | 12,846 | 34,570 | 1,621,782 | 0.0213 | 0.3150 | DGM |
| 3 | MAT2-TX-140-FY09-3 | 10,537 | 30,754 | 1,701,807 | 0.0181 | 0.3958 | DGM |
| 4 | MAT2-TX-140-FY09-4 | 10,472 | 30,354 | 1,405,093 | 0.0216 | 0.5082 | DGM |
| 5 | MAT2-TX-140-FY09-5 | 12,053 | 31,829 | 1,884,774 | 0.0169 | 0.3791 | DGM |
| Average | | 11,021 | 30,979 | 1,663,892 | 0.0189 | 0.4277 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the in-plane tensile strength, elastic modulus, and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint is used to eliminate all moments about the fixed lower head and allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) 9 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See E-14 to E-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-1-140-FY09**
 Test Date: 7/11/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 12,936 lbs
 Tensile Strength, ST_x : 34,006 psi
 Tensile Modulus, E_x : 1,277,320 psi
 Ultimate Strain, ϵ_x : 0.0266 in/in
 Poisson's Ratio, ν_{xy} : 0.3853

Measured Specimen Dimensions:

Width, W: 0.5095 in
 Thickness, H: 0.7466 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,587 lbs
 50% Max Load: 6,468 lbs

PICTURE OF SPECIMEN PRE-TEST



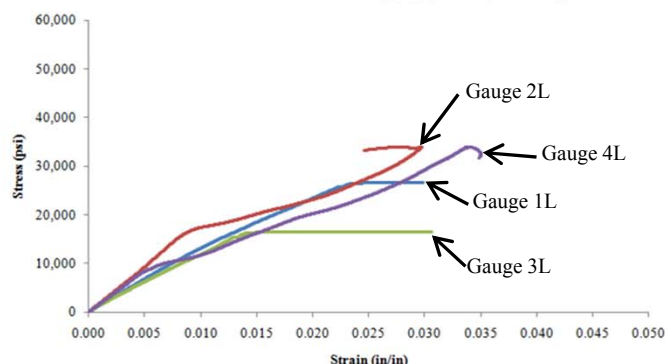
PICTURE OF SPECIMEN POST-TEST



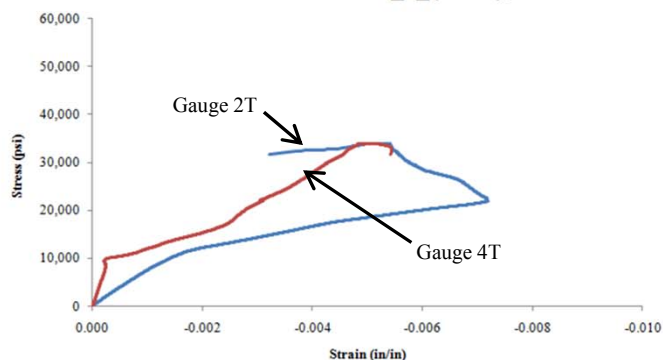
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0136 | 0.0050 | 1,183,076 | | | | |
| 2L | 0.0094 | 0.0037 | 1,787,985 | 2T | -0.0041 | -0.0009 | 0.5685 |
| 3L | 0.0139 | 0.0055 | 1,204,388 | | | | |
| 4L | 0.0149 | 0.0040 | 933,831 | 4T | -0.0024 | -0.0002 | 0.2022 |
| Average | | | 1,277,320 | | | | 0.3853 |

Stress-Strain Curve 140°F_1_(09-02), Long.



Stress-Strain Curve 140°F_1_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-2-140-FY09**
 Test Date: 7/15/2011
 Specimen Received: 4/22/2011
 Properties Measured: ST_x , E_x , v_{xy}

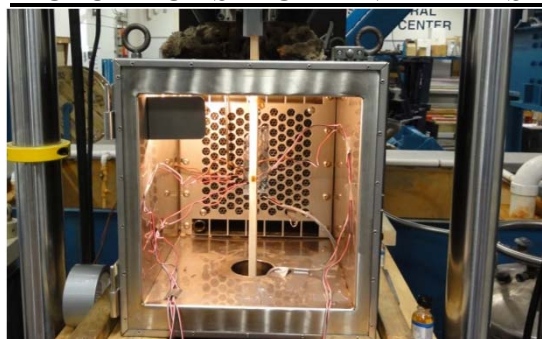
Average Material Properties:

Ultimate Load, P_x : 12,846 lbs
 Tensile Strength, ST_x : 34,570 psi
 Tensile Modulus, E_x : 1,621,782 psi
 Ultimate Strain, ϵ_x : 0.0213 in/in
 Poisson's Ratio, v_{xy} : 0.3150

Measured Specimen Dimensions:

Width, W: 0.4929 in
 Thickness, H: 0.7539 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,569 lbs
 50% Max Load: 6,423 lbs

PICTURE OF SPECIMEN PRE-TEST



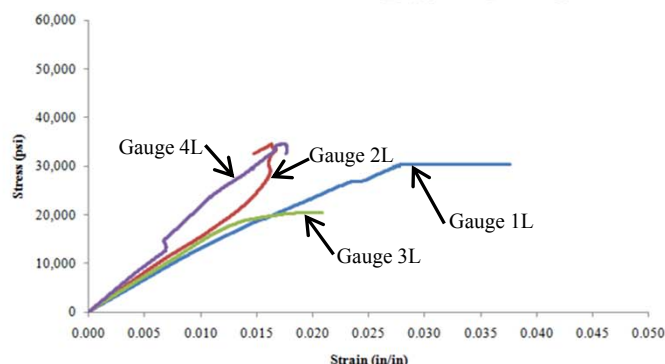
PICTURE OF SPECIMEN POST-TEST



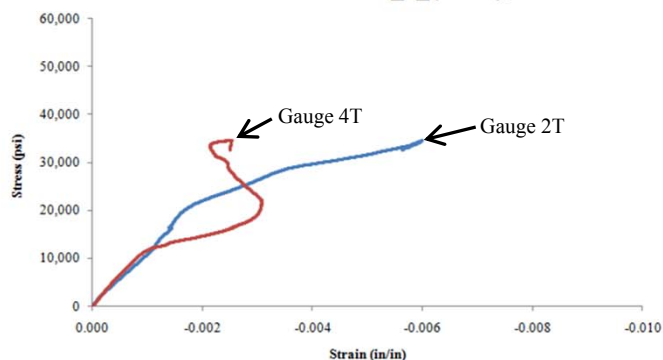
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0137 | 0.0052 | 1,215,259 | | | | |
| 2L | 0.0111 | 0.0042 | 1,502,839 | 2T | -0.0015 | -0.0006 | 0.1233 |
| 3L | 0.0121 | 0.0047 | 1,391,151 | | | | |
| 4L | 0.0079 | 0.0036 | 2,377,878 | 4T | -0.0027 | -0.0005 | 0.5068 |
| Average | | | 1,621,782 | | | | 0.3150 |

Stress-Strain Curve 140°F_2_(09-02), Long.



Stress-Strain Curve 140°F_2_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-3-140-FY09**
 Test Date: 7/21/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_x , E_x , ν_{xy}

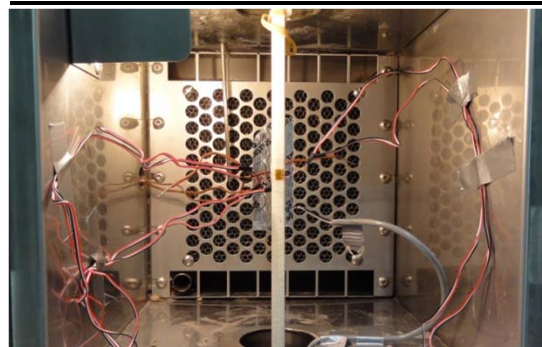
Average Material Properties:

Ultimate Load, P_x : 10,537 lbs
 Tensile Strength, ST_x : 30,754 psi
 Tensile Modulus, E_x : 1,701,807 psi
 Ultimate Strain, ϵ_x : 0.0181 in/in
 Poisson's Ratio, ν_{xy} : 0.3958

Measured Specimen Dimensions:

Width, W: 0.4644 in
 Thickness, H: 0.7378 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,107 lbs
 50% Max Load: 5,269 lbs

PICTURE OF SPECIMEN PRE-TEST



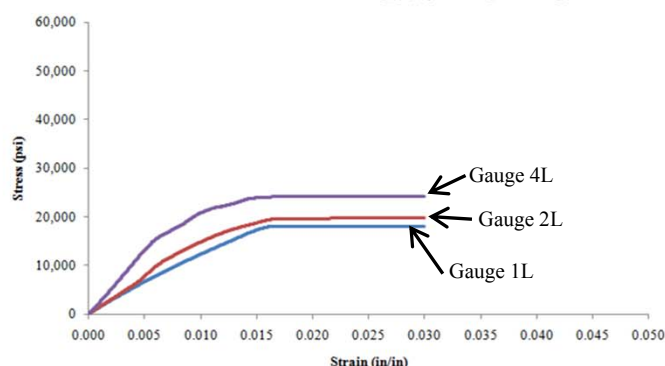
PICTURE OF SPECIMEN POST-TEST



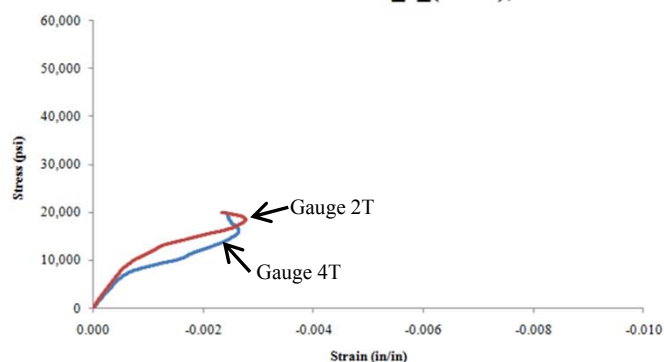
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0130 | 0.0046 | 1,093,447 | | | | |
| 2L | 0.0105 | 0.0041 | 1,436,386 | 2T | -0.0026 | -0.0005 | 0.3306 |
| 3L | Lost Gauge | | | | | | |
| 4L | 0.0060 | 0.0024 | 2,575,589 | 4T | -0.0020 | -0.0004 | 0.4611 |
| Average | | | 1,701,807 | | | | 0.3958 |

Stress-Strain Curve 140°F_3_(09-02), Long.



Stress-Strain Curve 140°F_3_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-4-140-FY09**
 Test Date: 7/21/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 10,472 lbs
 Tensile Strength, ST_x : 30,354 psi
 Tensile Modulus, E_x : 1,405,093 psi
 Ultimate Strain, ϵ_x : 0.0216 in/in
 Poisson's Ratio, v_{xy} : 0.5082

Measured Specimen Dimensions:

Width, W: 0.4681 in
 Thickness, H: 0.7370 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,094 lbs
 50% Max Load: 5,236 lbs

PICTURE OF SPECIMEN PRE-TEST



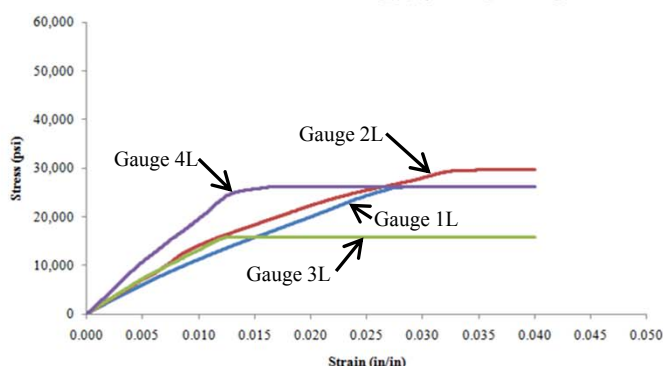
PICTURE OF SPECIMEN POST-TEST



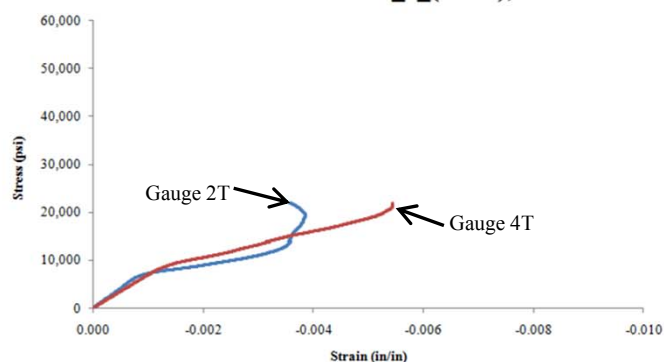
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0143 | 0.0050 | 978,333 | | | | |
| 2L | 0.0111 | 0.0043 | 1,328,293 | 2T | -0.0036 | -0.0007 | 0.4219 |
| 3L | 0.0109 | 0.0041 | 1,338,579 | | | | |
| 4L | 0.0074 | 0.0028 | 1,975,169 | 4T | -0.0036 | -0.0009 | 0.5946 |
| Average | | | 1,405,093 | | | | 0.5082 |

Stress-Strain Curve 140°F_4_(09-02), Long.



Stress-Strain Curve 140°F_4_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT2-TX-5-140-FY09**
 Test Date: 7/21/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_x , E_x , v_{xy}

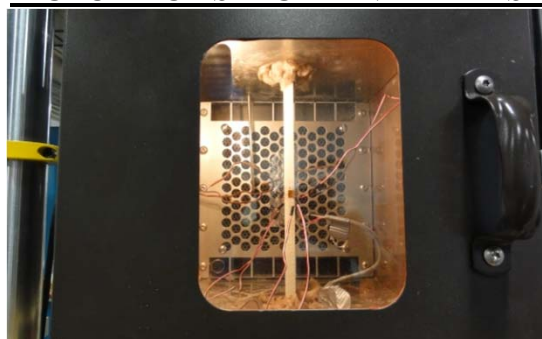
Average Material Properties:

Ultimate Load, P_x : 12,053 lbs
 Tensile Strength, ST_x : 31,829 psi
 Tensile Modulus, E_x : 1,884,774 psi
 Ultimate Strain, ϵ_x : 0.0169 in/in
 Poisson's Ratio, v_{xy} : 0.3791

Measured Specimen Dimensions:

Width, W: 0.5201 in
 Thickness, H: 0.7281 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,411 lbs
 50% Max Load: 6,027 lbs

PICTURE OF SPECIMEN PRE-TEST



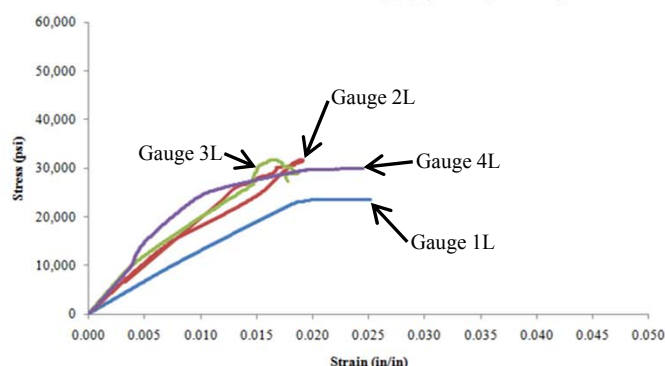
PICTURE OF SPECIMEN POST-TEST



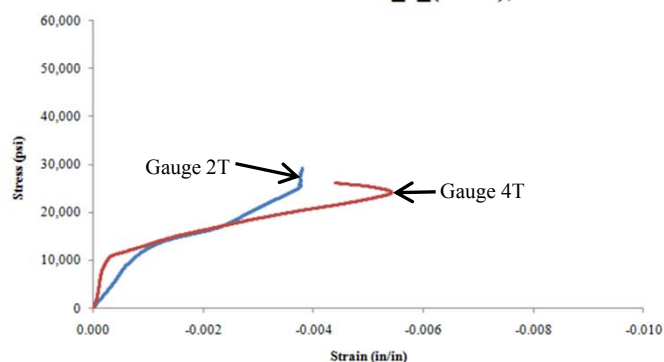
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0124 | 0.0047 | 1,244,178 | | | | |
| 2L | 0.0081 | 0.0029 | 1,839,921 | 2T | -0.0020 | -0.0004 | 0.2964 |
| 3L | 0.0074 | 0.0024 | 1,889,523 | | | | |
| 4L | 0.0037 | 0.0000 | 2,565,473 | 4T | -0.0018 | -0.0001 | 0.4617 |
| Average | | | 1,884,774 | | | | 0.3791 |

Stress-Strain Curve 140°F_5_(09-02), Long.



Stress-Strain Curve 140°F_5_(09-02), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-N40-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 27,529 lbs
 Compressive Strength, SC_x : 36,806 psi
 Compressive Modulus, E_x : 2,839,855 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.246

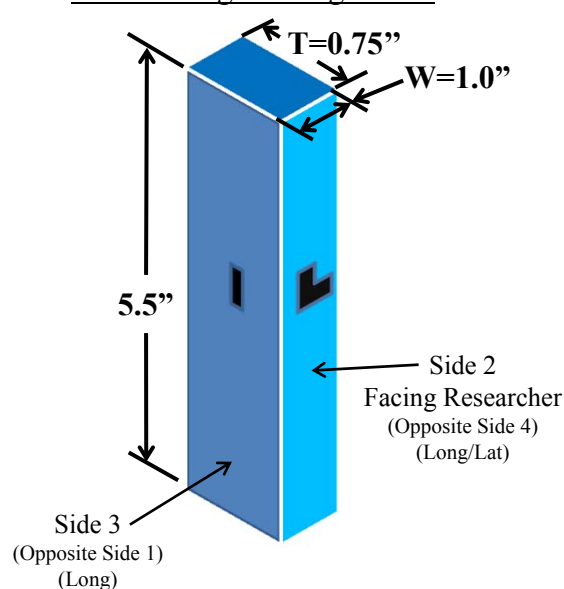
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT2-CX-01-N40-FY09 | 26,444 | 34,414 | 2,751,715 | 0.013 | 0.212 | Delamination |
| MAT2-CX-02-N40-FY09 | 27,151 | 35,215 | 2,731,616 | 0.013 | 0.282 | Delamination |
| MAT2-CX-03-N40-FY09 | 27,871 | 37,361 | 2,893,144 | 0.013 | 0.243 | Delamination |
| MAT2-CX-04-N40-FY09 | 27,651 | 38,077 | 3,044,585 | 0.013 | 0.226 | Delamination |
| MAT2-CX-05-N40-FY09 | 28,526 | 38,964 | 2,778,213 | 0.014 | 0.269 | Delamination |
| Average | 27,529 | 36,806 | 2,839,855 | 0.013 | 0.246 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See E-20 to E-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-01-N40-FY09
 Test Date: 6/24/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 26,444 lbs
 Compressive Strength, SC_x : 34,414 psi
 Compressive Modulus, E_x : 2,751,715 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.212

Measured Specimen Dimensions:

Width, W: 0.9940 in
 Thickness, H: 0.7730 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,289 lbs
 50% Max Load: 13,222 lbs

PICTURE OF SPECIMEN PRE-TEST



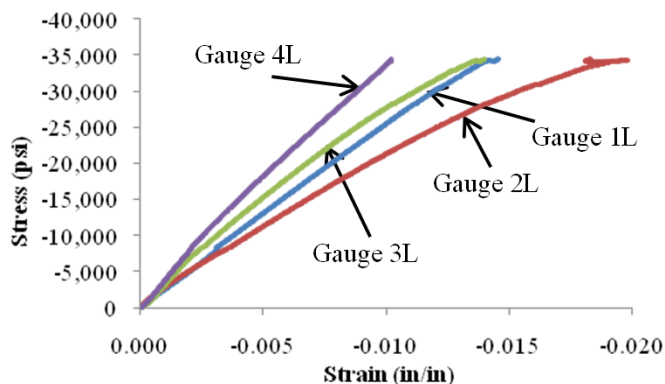
PICTURE OF SPECIMEN POST-TEST



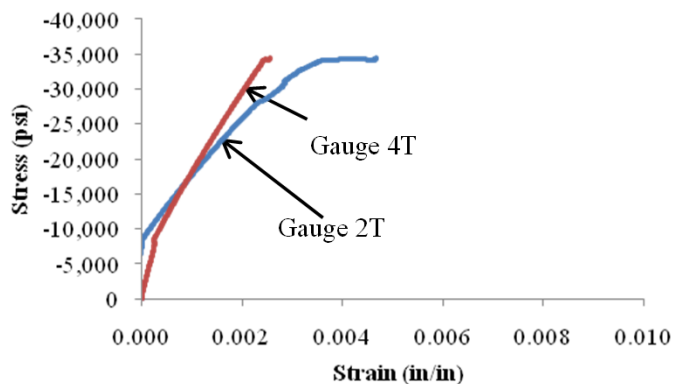
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00662 | -0.00270 | 2,633,705 | | | | |
| 2L | -0.00786 | -0.00283 | 2,052,559 | 2T | 0.00093 | -0.00002 | 0.189 |
| 3L | -0.00270 | -0.00201 | 2,797,015 | | | | |
| 4L | -0.00467 | -0.00174 | 3,523,580 | 4T | 0.00091 | 0.00023 | 0.234 |
| Average | | | 2,751,715 | | | | 0.212 |

Stress-Strain Curve N40_01_(09-02)_Long



Stress-Strain Curve N40_01_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-02-N40-FY09**
 Test Date: 6/24/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 27,151 lbs
 Compressive Strength, SC_x : 35,215 psi
 Compressive Modulus, E_x : 2,731,616 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.282

Measured Specimen Dimensions:

Width, W: 0.9780 in
 Thickness, H: 0.7710 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,430 lbs
 50% Max Load: 13,575 lbs

PICTURE OF SPECIMEN PRE-TEST



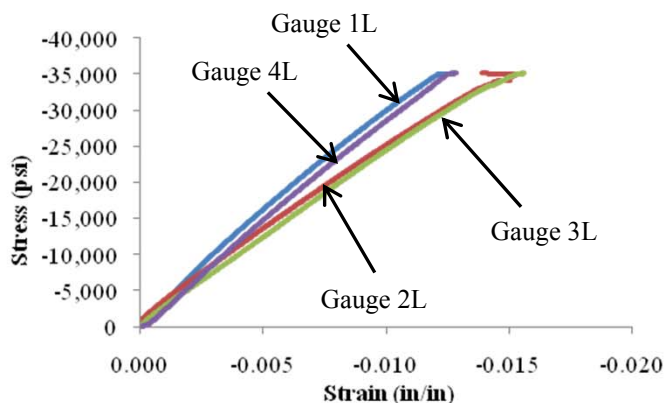
PICTURE OF SPECIMEN POST-TEST



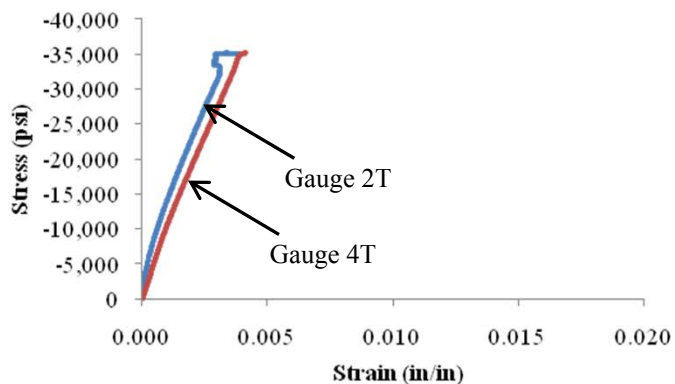
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00546 | -0.00202 | 3,073,875 | | | | |
| 2L | -0.00666 | -0.00229 | 2,421,221 | 2T | 0.00138 | 0.00036 | 0.234 |
| 3L | -0.00711 | -0.00275 | 2,424,248 | | | | |
| 4L | -0.00597 | -0.00246 | 3,007,121 | 4T | 0.00181 | 0.00065 | 0.331 |
| Average | | | 2,731,616 | | | | 0.282 |

Stress-Strain Curve N40_02_(09-02)_Long



Stress-Strain Curve N40_02_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-03-N40-FY09**
 Test Date: 6/24/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 27,871 lbs
 Compressive Strength, SC_x : 37,361 psi
 Compressive Modulus, E_x : 2,893,144 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.243

Measured Specimen Dimensions:

Width, W: 1.0100 in
 Thickness, H: 0.7535 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,574 lbs
 50% Max Load: 13,936 lbs

PICTURE OF SPECIMEN PRE-TEST



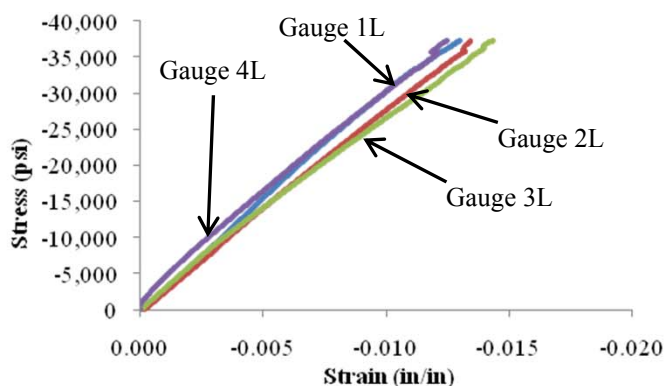
PICTURE OF SPECIMEN POST-TEST



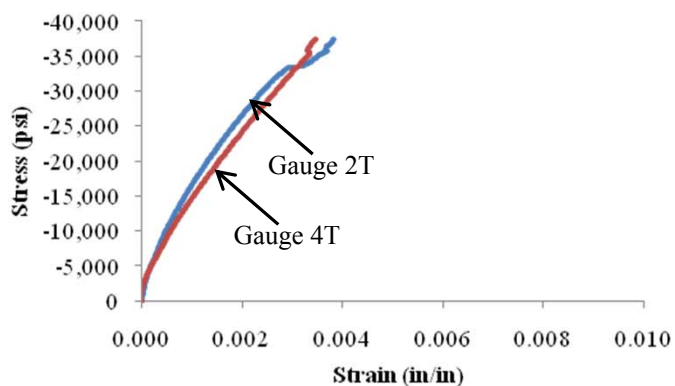
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00601 | -0.00250 | 3,195,335 | | | | |
| 2L | -0.00666 | -0.00275 | 2,869,857 | 2T | 0.00119 | 0.00032 | 0.221 |
| 3L | -0.00678 | -0.00248 | 2,607,858 | | | | |
| 4L | -0.00576 | -0.00190 | 2,899,526 | 4T | 0.00140 | 0.00038 | 0.266 |
| Average | | | 2,893,144 | | | | 0.243 |

Stress-Strain Curve N40_03_(09-02)_Long



Stress-Strain Curve N40_03_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-04-N40-FY09
 Test Date: 6/27/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 27,651 lbs
 Compressive Strength, SC_x : 38,077 psi
 Compressive Modulus, E_x : 3,044,585 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, v_{xy} : 0.226

Measured Specimen Dimensions:

Width, W: 0.9700 in
 Thickness, H: 0.7490 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,530 lbs
 50% Max Load: 13,826 lbs

PICTURE OF SPECIMEN PRE-TEST



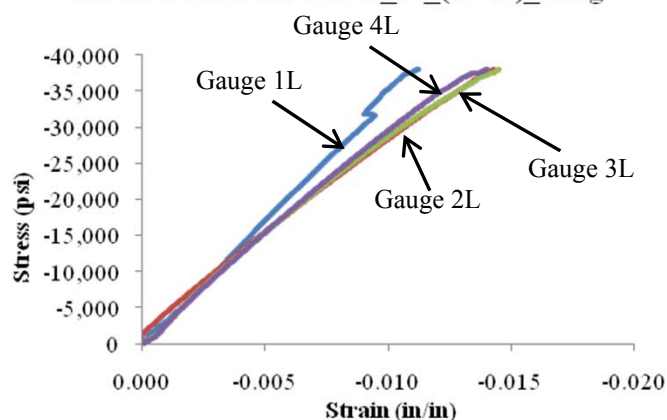
PICTURE OF SPECIMEN POST-TEST



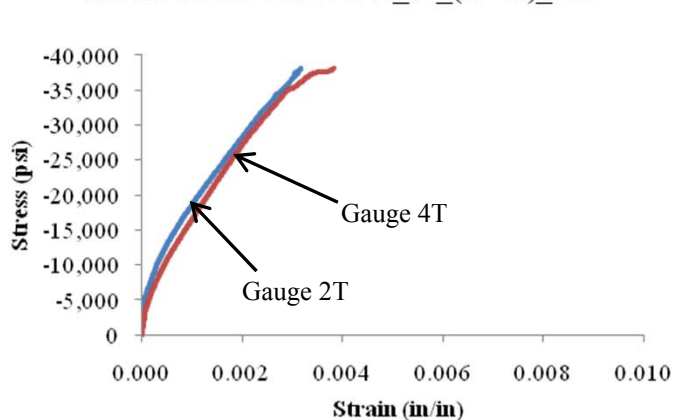
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00557 | -0.00235 | 3,546,749 | | | | |
| 2L | -0.00632 | -0.00211 | 2,712,850 | 2T | 0.00104 | 0.00018 | 0.205 |
| 3L | -0.00630 | -0.00238 | 2,909,943 | | | | |
| 4L | -0.00622 | -0.00243 | 3,008,797 | 4T | 0.00122 | 0.00028 | 0.247 |
| Average | | | 3,044,585 | | | | 0.226 |

Stress-Strain Curve N40_04_(09-02)_Long



Stress-Strain Curve N40_04_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-05-N40-FY09**
 Test Date: 6/27/2011
 Specimen Received: 5/20/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 28,526 lbs
 Compressive Strength, SC_x : 38,964 psi
 Compressive Modulus, E_x : 2,778,213 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.269

Measured Specimen Dimensions:

Width, W: 0.9840 in
 Thickness, H: 0.7440 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,705 lbs
 50% Max Load: 14,263 lbs

PICTURE OF SPECIMEN PRE-TEST



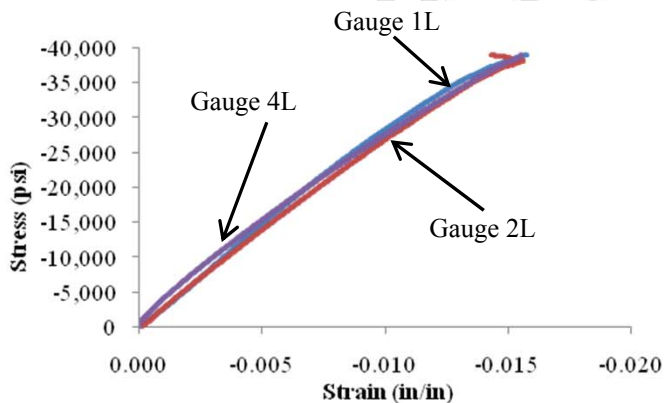
PICTURE OF SPECIMEN POST-TEST



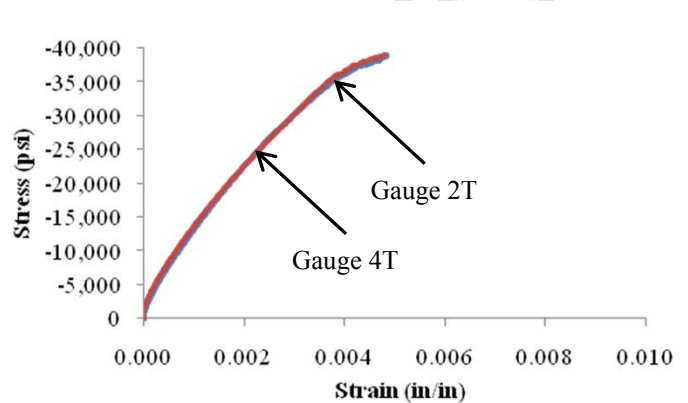
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00663 | -0.00272 | 2,987,466 | | | | |
| 2L | -0.00709 | -0.00275 | 2,692,470 | 2T | 0.00166 | 0.00049 | 0.268 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.00661 | -0.00221 | 2,654,704 | 4T | 0.00163 | 0.00044 | 0.270 |
| Average | | | 2,778,213 | | | | 0.269 |

Stress-Strain Curve N40_05_(09-02)_Long



Stress-Strain Curve N40_05_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Longitudinal strain gauge three was lost

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

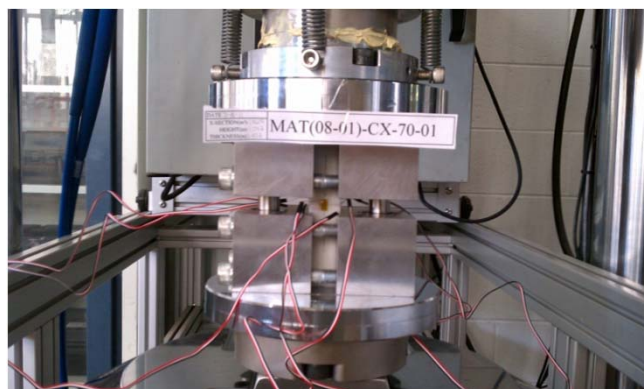
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-70-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 19,611 lbs
 Compressive Strength, SC_x : 26,695 psi
 Compressive Modulus, E_x : 2,730,500 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.206

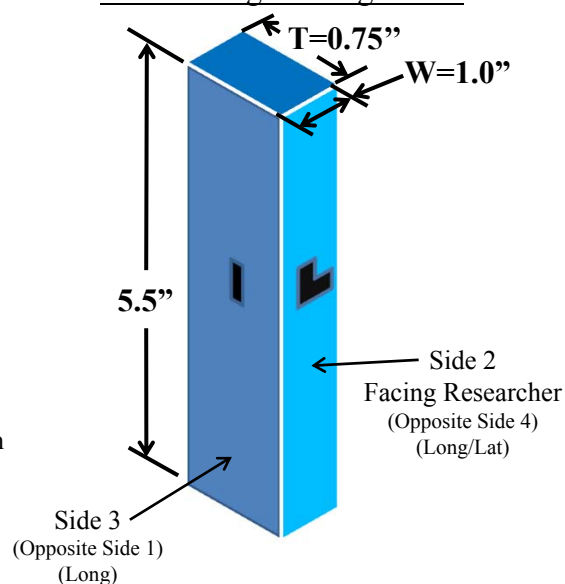
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT2-CX-01-70-FY09 | 18,790 | 25,578 | 2,825,922 | 0.009 | 0.175 | Delamination |
| MAT2-CX-02-70-FY09 | 19,876 | 27,072 | 2,627,825 | 0.010 | 0.226 | Delamination |
| MAT2-CX-03-70-FY09 | 19,367 | 25,910 | 2,607,044 | 0.010 | 0.196 | Delamination |
| MAT2-CX-04-70-FY09 | 19,279 | 26,585 | 2,744,990 | 0.010 | 0.207 | Delamination |
| MAT2-CX-05-70-FY09 | 20,745 | 28,329 | 2,846,719 | 0.010 | 0.226 | Delamination |
| Average | 19,611 | 26,695 | 2,730,500 | 0.010 | 0.206 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See E-26 to E-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-01-70-FY09**
 Test Date: 6/16/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 18,790 lbs
 Compressive Strength, SC_x : 25,578 psi
 Compressive Modulus, E_x : 2,825,922 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.175

Measured Specimen Dimensions:

Width, W: 0.9900 in
 Thickness, H: 0.7420 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,758 lbs
 50% Max Load: 9,395 lbs

PICTURE OF SPECIMEN PRE-TEST



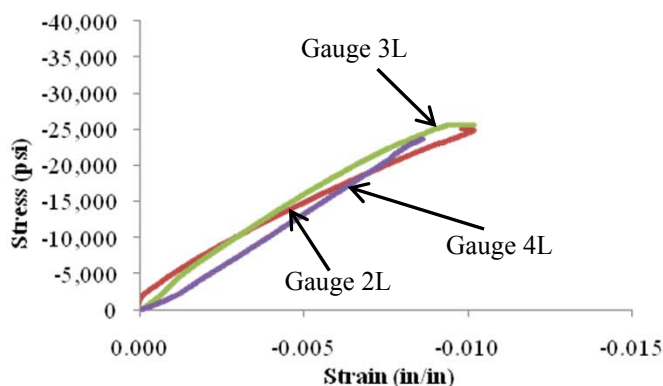
PICTURE OF SPECIMEN POST-TEST



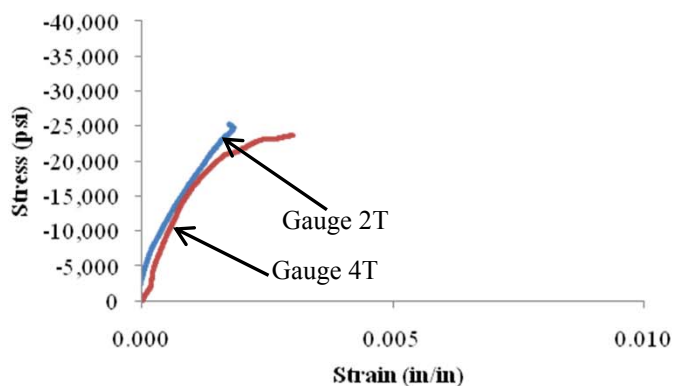
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.00407 | -0.00103 | 2,529,514 | 2T | 0.00060 | 0.00007 | 0.173 |
| 3L | -0.00385 | -0.00134 | 3,058,862 | | | | |
| 4L | -0.00483 | -0.00217 | 2,889,390 | 4T | 0.00072 | 0.00025 | 0.177 |
| Average | | | 2,825,922 | | | | 0.175 |

Stress-Strain Curve 70F_01_(09-02)_Long



Stress-Strain Curve 70F_01_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-02-70-FY09**
 Test Date: 6/16/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 19,876 lbs
 Compressive Strength, SC_x : 27,072 psi
 Compressive Modulus, E_x : 2,627,825 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.226

Measured Specimen Dimensions:

Width, W: 0.9750 in
 Thickness, H: 0.7530 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,975 lbs
 50% Max Load: 9,938 lbs

PICTURE OF SPECIMEN PRE-TEST



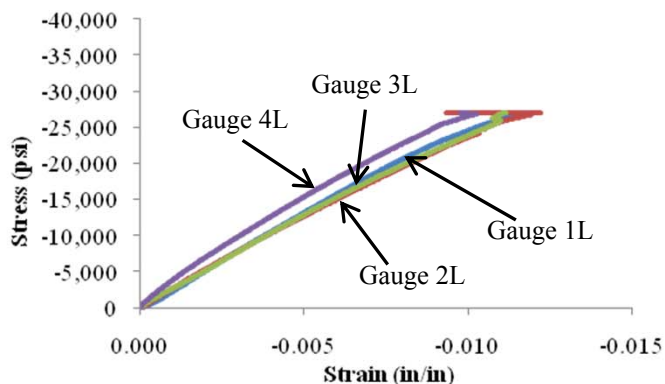
PICTURE OF SPECIMEN POST-TEST



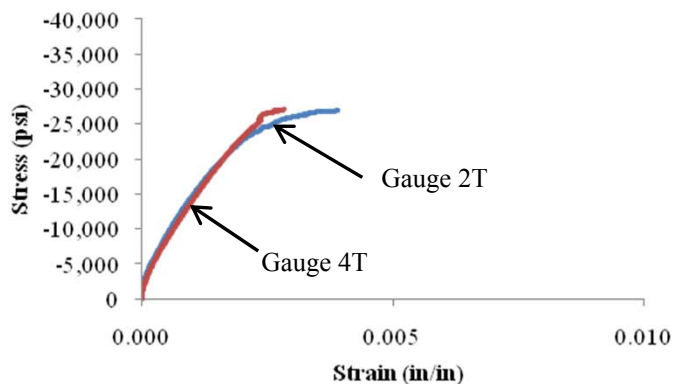
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00513 | -0.00207 | 2,654,961 | | | | |
| 2L | -0.00534 | -0.00200 | 2,435,161 | 2T | 0.00088 | 0.00021 | 0.202 |
| 3L | -0.00524 | -0.00207 | 2,560,684 | | | | |
| 4L | -0.00430 | -0.00146 | 2,860,496 | 4T | 0.00095 | 0.00025 | 0.249 |
| Average | | | 2,627,825 | | | | 0.226 |

Stress-Strain Curve 70F_02_(09-02)_Long



Stress-Strain Curve 70F_02_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-03-70-FY09**
 Test Date: 6/16/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 19,367 lbs
 Compressive Strength, SC_x : 25,910 psi
 Compressive Modulus, E_x : 2,607,044 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.196

Measured Specimen Dimensions:

Width, W: 0.9900 in
 Thickness, H: 0.7550 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,873 lbs
 50% Max Load: 9,684 lbs

PICTURE OF SPECIMEN PRE-TEST



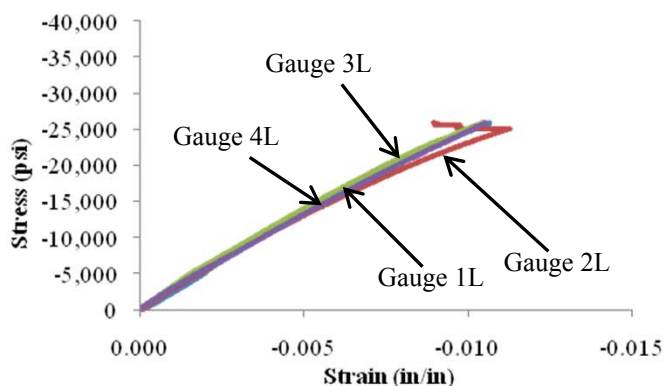
PICTURE OF SPECIMEN POST-TEST



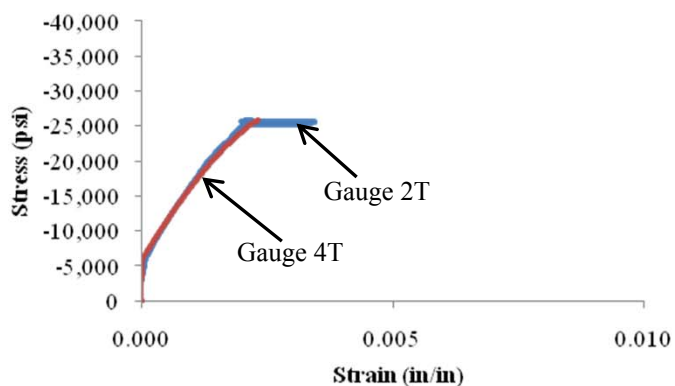
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | .000478 | -0.00198 | 2,774,962 | | | | |
| 2L | -0.00492 | -0.00183 | 2,534,948 | 2T | 0.00063 | 0.00005 | 0.190 |
| 3L | -0.00456 | -0.00157 | 2,601,211 | | | | |
| 4L | -0.00487 | -0.00178 | 2,517,054 | 4T | 0.00064 | 0.00001 | 0.201 |
| Average | | | 2,607,044 | | | | 0.196 |

Stress-Strain Curve 70F_03_(09-02)_Long



Stress-Strain Curve 70F_03_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-04-70-FY09**
 Test Date: 6/17/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 19,279 lbs
 Compressive Strength, SC_x : 26,585 psi
 Compressive Modulus, E_x : 2,744,990 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.207

Measured Specimen Dimensions:

Width, W: 0.9800 in
 Thickness, H: 0.7400 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,856 lbs
 50% Max Load: 9,640 lbs

PICTURE OF SPECIMEN PRE-TEST



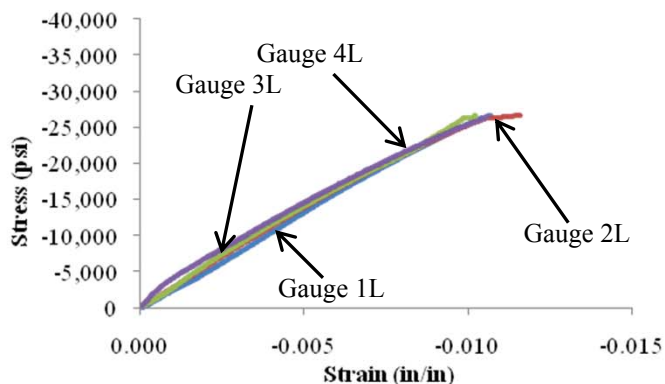
PICTURE OF SPECIMEN POST-TEST



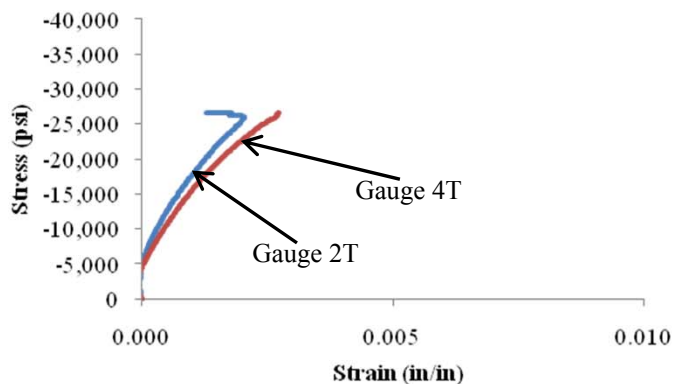
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00501 | -0.00217 | 2,801,869 | | | | |
| 2L | -0.00474 | -0.00186 | 2,775,303 | 2T | 0.00056 | 0.00002 | 0.187 |
| 3L | -0.00467 | -0.00179 | 2,775,303 | | | | |
| 4L | -0.00446 | -0.00142 | 2,627,486 | 4T | 0.00075 | 0.00006 | 0.228 |
| Average | | | 2,744,990 | | | | 0.207 |

Stress-Strain Curve 70F_04_(09-02)_Long



Stress-Strain Curve 70F_04_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-05-70-FY09**
 Test Date: 6/17/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 20,745 lbs
 Compressive Strength, SC_x : 28,329 psi
 Compressive Modulus, E_x : 2,846,719 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : 0.226

Measured Specimen Dimensions:

Width, W: 0.9950 in
 Thickness, H: 0.7360 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,149 lbs
 50% Max Load: 10,373 lbs

PICTURE OF SPECIMEN PRE-TEST



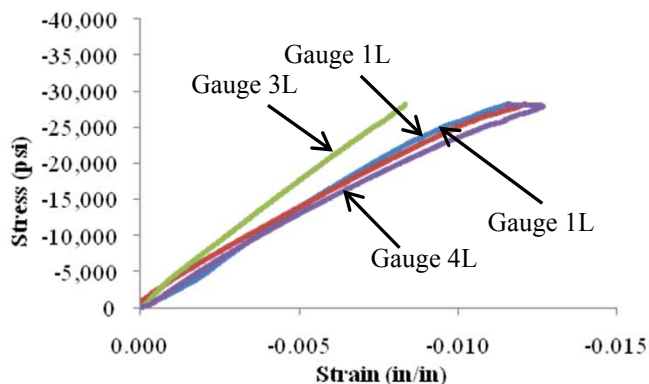
PICTURE OF SPECIMEN POST-TEST



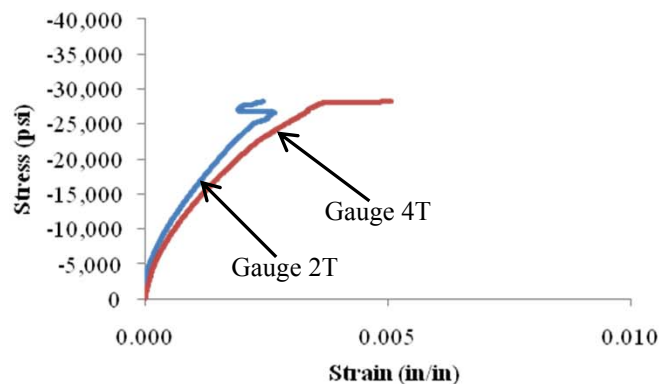
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00511 | -0.00231 | 3,041,973 | | | | |
| 2L | -0.00509 | -0.00167 | 2,483,309 | 2T | 0.00084 | 0.00014 | 0.206 |
| 3L | -0.00395 | -0.00142 | 3,361,030 | | | | |
| 4L | -0.00549 | -0.00209 | 2,500,563 | 4T | 0.00108 | 0.00025 | 0.245 |
| Average | | | 2,846,719 | | | | 0.226 |

Stress-Strain Curve 70F_05_(09-02)_Long



Stress-Strain Curve 70F_05_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CX-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 7,808 lbs
 Compressive Strength, SC_x : 10,486 psi
 Compressive Modulus, E_x : 2,244,152 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.297

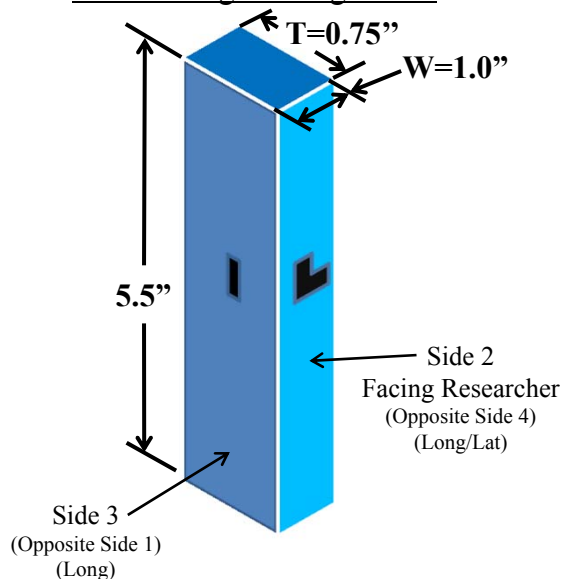
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT2-CX-01-140-FY09 | 7,987 | 10,639 | 2,322,430 | 0.005 | 0.302 | Delamination |
| MAT2-CX-02-140-FY09 | 7,924 | 10,650 | 2,030,410 | 0.005 | 0.281 | Delamination |
| MAT2 CX-03-140-FY09 | 7,514 | 10,165 | 2,466,111 | 0.004 | 0.344 | Delamination |
| MAT2-CX-04-140-FY09 | 8,023 | 10,654 | 2,343,959 | 0.005 | 0.305 | Delamination |
| MAT2-CX-05-140-FY09 | 7,594 | 10,324 | 2,057,848 | 0.005 | 0.255 | Delamination |
| Average | 7,808 | 10,486 | 2,244,152 | 0.005 | 0.297 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641 measures the in-plane compressive strength, compressive modulus, and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width, W.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See E-32 to E-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-01-140-FY09**
 Test Date: 6/23/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 7,987 lbs
 Compressive Strength, SC_x : 10,639 psi
 Compressive Modulus, E_x : 2,322,430 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.302

Measured Specimen Dimensions:

Width, W: 0.9970 in
 Thickness, H: 0.7530 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,597 lbs
 50% Max Load: 3,993 lbs

PICTURE OF SPECIMEN PRE-TEST



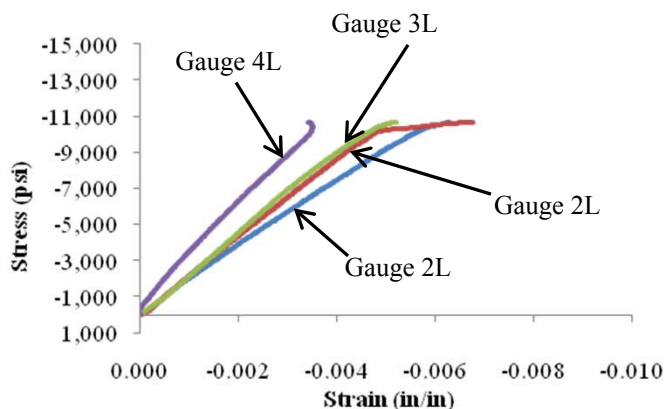
PICTURE OF SPECIMEN POST-TEST



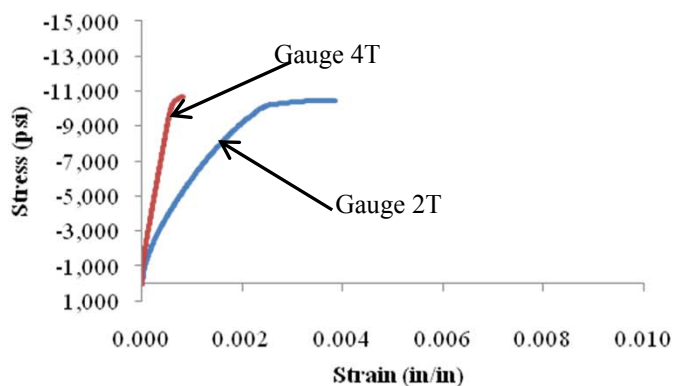
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00277 | -0.00103 | 1,841,783 | | | | |
| 2L | -0.00244 | -0.00096 | 2,163,868 | 2T | 0.00082 | 0.00019 | 0.428 |
| 3L | -0.00231 | -0.00098 | 2,403,640 | | | | |
| 4L | -0.00163 | -0.00052 | 2,880,428 | 4T | 0.00141 | 0.00007 | 0.176 |
| Average | | | 2,322,430 | | | | 0.302 |

Stress-Strain Curve 140F_01_(09-02)_Long



Stress-Strain Curve 140F_01_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT2-CX-02-140-FY09**
 Test Date: 6/17/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 7,924 lbs
 Compressive Strength, SC_x : 10,650 psi
 Compressive Modulus, E_x : 2,030,410 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.281

Measured Specimen Dimensions:

Width, W: 1.0000 in
 Thickness, H: 0.7440 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,585 lbs
 50% Max Load: 3,962 lbs

PICTURE OF SPECIMEN PRE-TEST



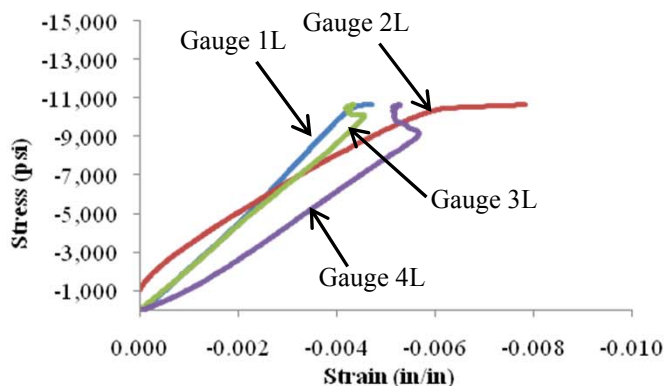
PICTURE OF SPECIMEN POST-TEST



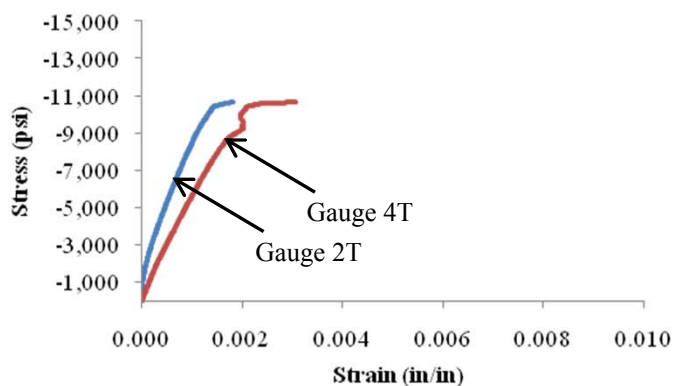
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00232 | -0.00097 | 2,364,035 | | | | |
| 2L | -0.00216 | -0.00034 | 1,760,603 | 2T | 0.00050 | 0.00009 | 0.224 |
| 3L | -0.00241 | -0.00099 | 2,243,421 | | | | |
| 4L | -0.00352 | -0.00170 | 1,753,582 | 4T | 0.00093 | 0.00032 | 0.337 |
| Average | | | 2,030,410 | | | | 0.281 |

Stress-Strain Curve 140F_02_(09-02)_Long



Stress-Strain Curve 140F_02_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-03-140-FY09
 Test Date: 6/20/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 7,514 lbs
 Compressive Strength, SC_x : 10,165 psi
 Compressive Modulus, E_x : 2,466,111 psi
 Ultimate Strain, ϵ_x : 0.004 in/in
 Poisson's Ratio, v_{xy} : 0.344

Measured Specimen Dimensions:

Width, W: 0.9830 in
 Thickness, H: 0.7520 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,503 lbs
 50% Max Load: 3,757 lbs

PICTURE OF SPECIMEN PRE-TEST



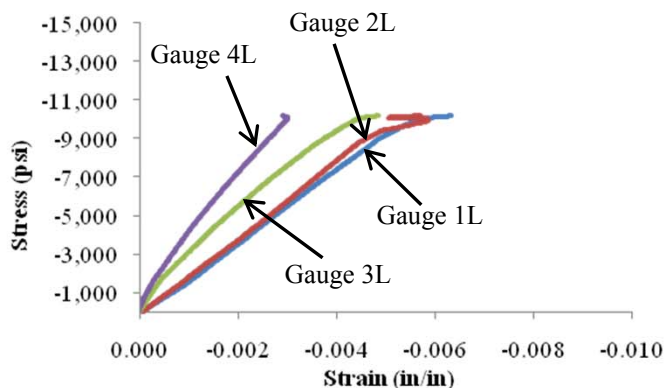
PICTURE OF SPECIMEN POST-TEST



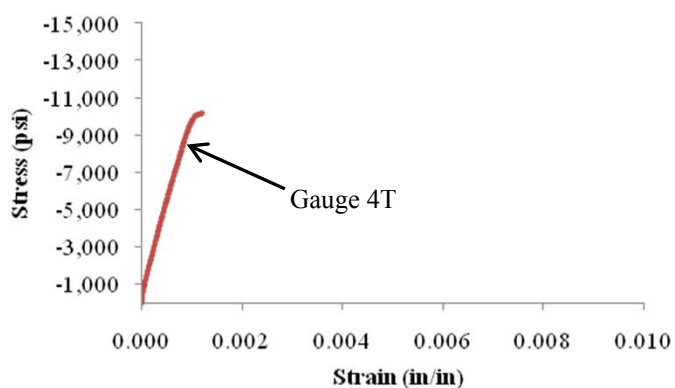
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00277 | -0.00123 | 1,974,951 | | | | |
| 2L | -0.00266 | -0.00109 | 1,945,201 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00180 | -0.00056 | 2,454,252 | | | | |
| 4L | -0.00126 | -0.00038 | 3,490,039 | 4T | 0.00045 | 0.00015 | 0.344 |
| Average | | | 2,466,111 | | | | 0.344 |

Stress-Strain Curve 140F_03_(09-02)_Long



Stress-Strain Curve 140F_03_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-04-140-FY09
 Test Date: 6/20/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 8,023 lbs
 Compressive Strength, SC_x : 10,654 psi
 Compressive Modulus, E_x : 2,343,959 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, v_{xy} : 0.305

Measured Specimen Dimensions:

Width, W: 1.0000 in
 Thickness, H: 0.7530 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,605 lbs
 50% Max Load: 4,011 lbs

PICTURE OF SPECIMEN PRE-TEST



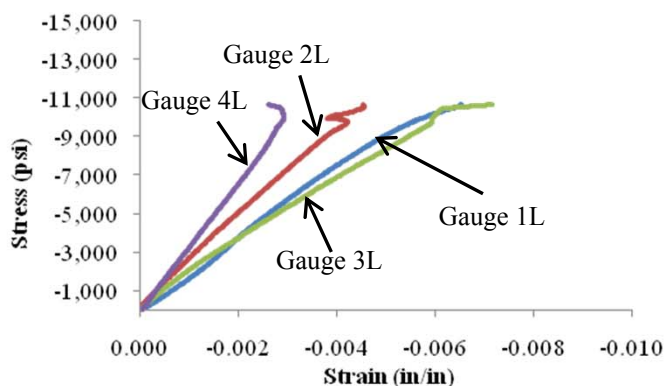
PICTURE OF SPECIMEN POST-TEST



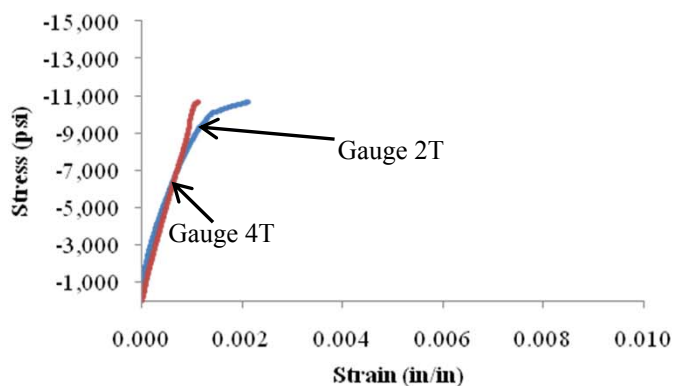
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00278 | -0.00125 | 2,097,182 | | | | |
| 2L | -0.00211 | -0.00076 | 2,371,342 | 2T | 0.00046 | 0.00009 | 0.273 |
| 3L | -0.00298 | -0.00102 | 1,630,710 | | | | |
| 4L | -0.00162 | -0.00065 | 3,276,603 | 4T | 0.00052 | 0.00019 | 0.337 |
| Average | | | 2,343,959 | | | | 0.305 |

Stress-Strain Curve 140F_04_(09-02)_Long



Stress-Strain Curve 140F_04_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT2-CX-05-140-FY09
 Test Date: 6/20/2011
 Specimen Received: 4/22/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 7,594 lbs
 Compressive Strength, SC_x : 10,324 psi
 Compressive Modulus, E_x : 2,057,848 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.255

Measured Specimen Dimensions:

Width, W: 0.9980 in
 Thickness, H: 0.7370 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,519 lbs
 50% Max Load: 3,797 lbs

PICTURE OF SPECIMEN PRE-TEST



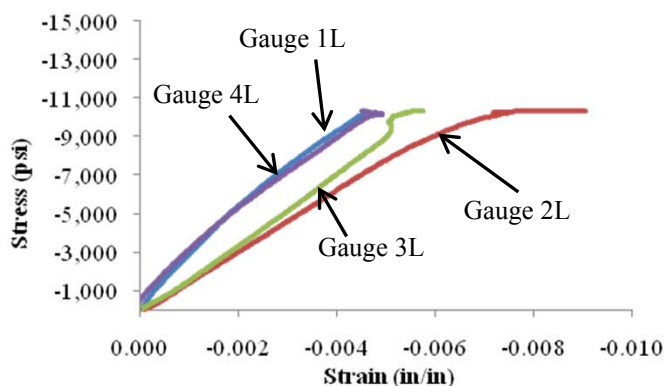
PICTURE OF SPECIMEN POST-TEST



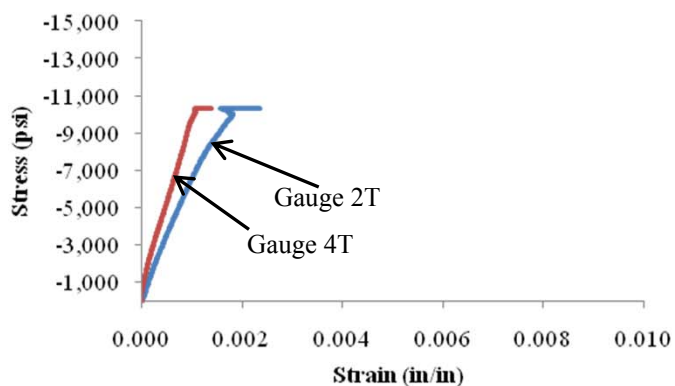
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00188 | -0.00067 | 2,552,489 | | | | |
| 2L | -0.00334 | -0.00140 | 1,593,516 | 2T | 0.00076 | 0.00027 | 0.252 |
| 3L | -0.00300 | -0.00130 | 1,811,969 | | | | |
| 4L | -0.00191 | -0.00054 | 2,273,417 | 4T | 0.00048 | 0.00013 | 0.259 |
| Average | | | 2,057,848 | | | | 0.255 |

Stress-Strain Curve 140F_05_(09-02)_Long



Stress-Strain Curve 140F_05_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

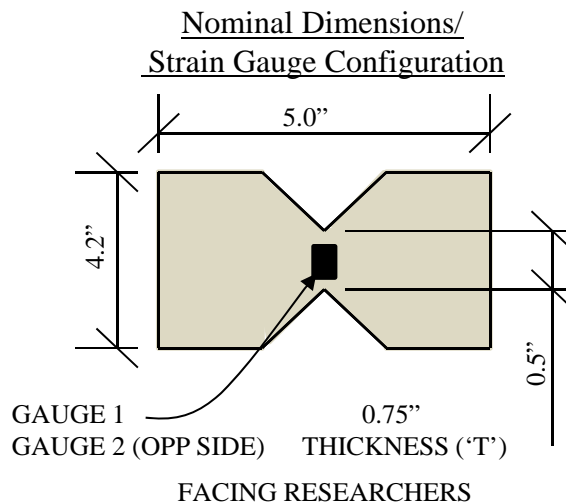
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXY-N40-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **12,396** **lbs**
 Shear Strength, S_{xy} : **28,345** **psi**
 Shear Modulus, G_{xy} : **1,316,192** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT2-SXY-01-N40-FY09 | 12,054 | 28,165 | 1,289,678 | Shear |
| 2 | MAT2-SXY-02-N40-FY09 | 11,642 | 26,702 | 1,280,884 | Shear |
| 3 | MAT2-SXY-03-N40-FY09 | 13,119 | 29,349 | 1,475,251 | Shear |
| 4 | MAT2-SXY-04-N40-FY09 | 13,009 | 28,973 | 1,301,666 | Shear |
| 5 | MAT2-SXY-05-N40-FY09 | 12,156 | 28,536 | 1,233,480 | Shear |
| Average | | 12,396 | 28,345 | 1,316,192 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets E-38 to E-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-N40-FY09
 Test Date: 7/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,054 lbs
 Shear Strength, S_{xy} : 28,165 psi
 Shear Modulus, G_{xy} : 1,289,678 psi

Measured Specimen Dimensions:

Thickness, T: 0.758 in
 Notch Length, N: 0.565 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,411 lbs
 50% Max Load: 6,027 lbs

PICTURE OF SPECIMEN PRE-TEST



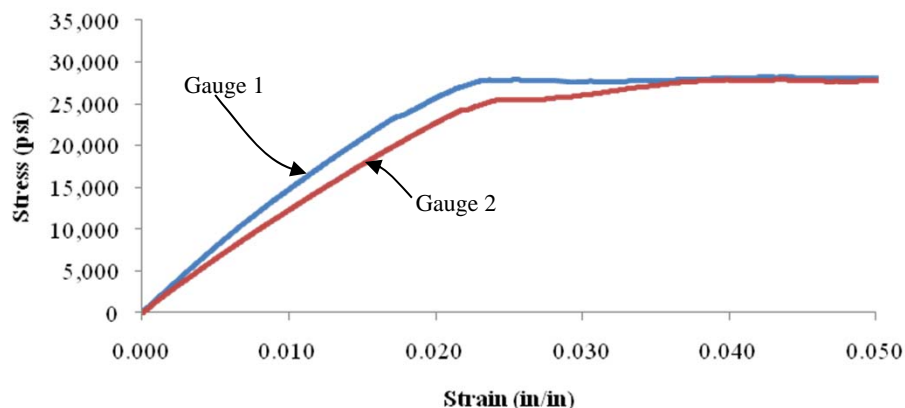
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00945 | 0.00350 | 1,420,202 |
| 2 | 0.01159 | 0.00431 | 1,159,154 |
| Average | | | 1,289,678 |

Stress-Strain Curve N40_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-N40-FY09
 Test Date: 7/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,642 lbs
 Shear Strength, S_{xy} : 26,702 psi
 Shear Modulus, G_{xy} : 1,280,884 psi

Measured Specimen Dimensions:

Thickness, T: 0.756 in
 Notch Length, N: 0.576 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,328 lbs
 50% Max Load: 5,821 lbs

PICTURE OF SPECIMEN PRE-TEST



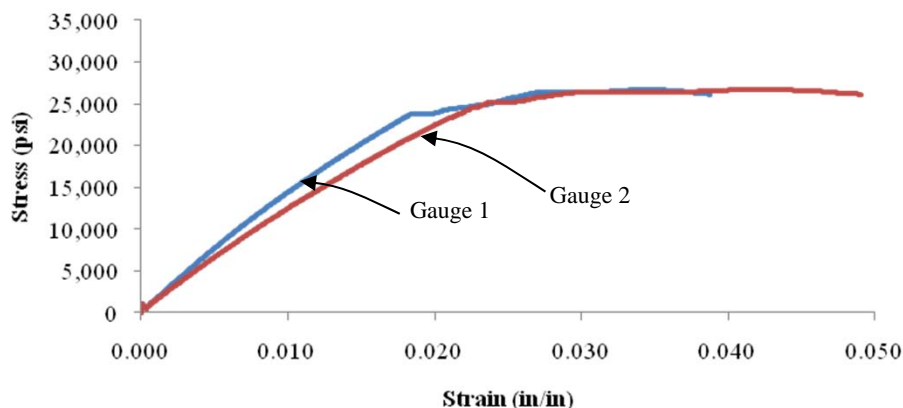
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00911 | 0.00334 | 1,390,346 |
| 2 | 0.01074 | 0.00390 | 1,171,421 |
| Average | | | 1,280,884 |

Stress-Strain Curve N40_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-N40-FY09
 Test Date: 8/1/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 13,119 lbs
 Shear Strength, S_{xy} : 29,349 psi
 Shear Modulus, G_{xy} : 1,475,251 psi

Measured Specimen Dimensions:

Thickness, T: 0.760 in
 Notch Length, N: 0.588 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,624 lbs
 50% Max Load: 6,559 lbs

PICTURE OF SPECIMEN PRE-TEST



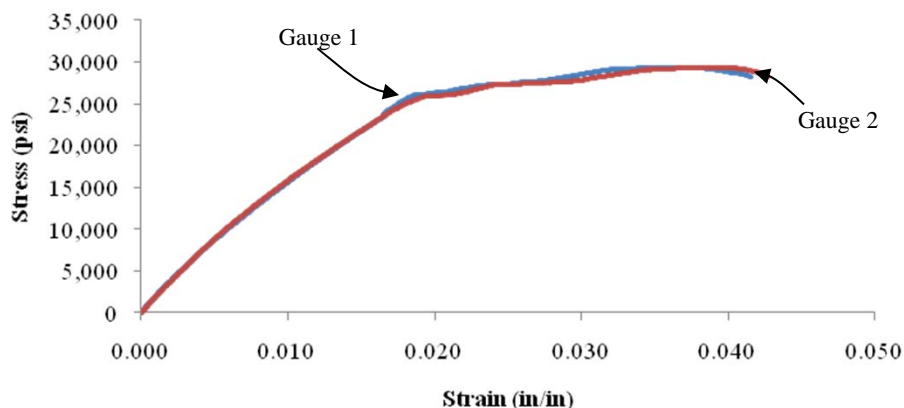
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00924 | 0.00320 | 1,456,442 |
| 2 | 0.00910 | 0.00321 | 1,494,060 |
| Average | | | 1,475,251 |

Stress-Strain Curve N40_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-N40-FY09
 Test Date: 8/1/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 13,009 lbs
 Shear Strength, S_{xy} : 28,973 psi
 Shear Modulus, G_{xy} : 1,301,666 psi

Measured Specimen Dimensions:

Thickness, T: 0.756 in
 Notch Length, N: 0.594 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,602 lbs
 50% Max Load: 6,504 lbs

PICTURE OF SPECIMEN PRE-TEST



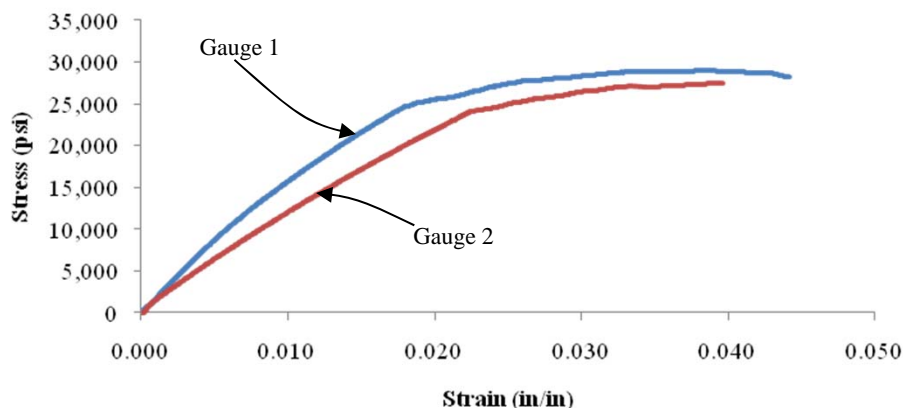
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00903 | 0.00324 | 1,501,262 |
| 2 | 0.01231 | 0.00443 | 1,102,070 |
| Average | | | 1,301,666 |

Stress-Strain Curve N40_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-N40-FY09
 Test Date: 8/2/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,156 lbs
 Shear Strength, S_{xy} : 28,536 psi
 Shear Modulus, G_{xy} : 1,233,480 psi

Measured Specimen Dimensions:

Thickness, T: 0.756 in
 Notch Length, N: 0.564 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,431 lbs
 50% Max Load: 6,078 lbs

PICTURE OF SPECIMEN PRE-TEST



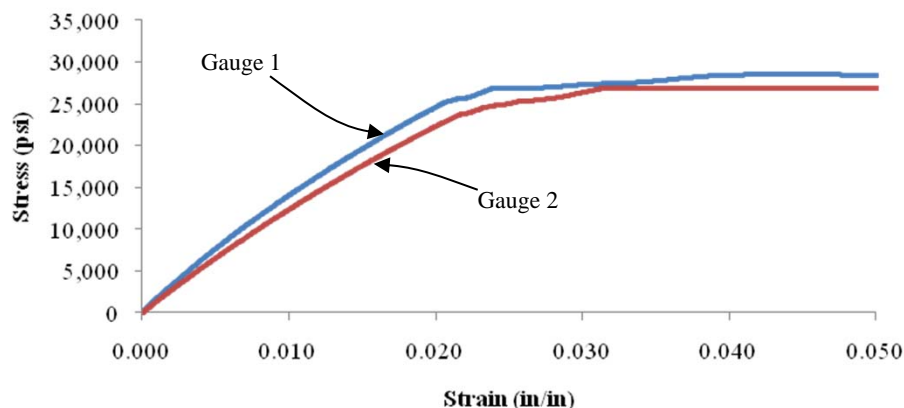
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01016 | 0.00362 | 1,309,835 |
| 2 | 0.01173 | 0.00433 | 1,157,126 |
| Average | | | 1,233,480 |

Stress-Strain Curve N40_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

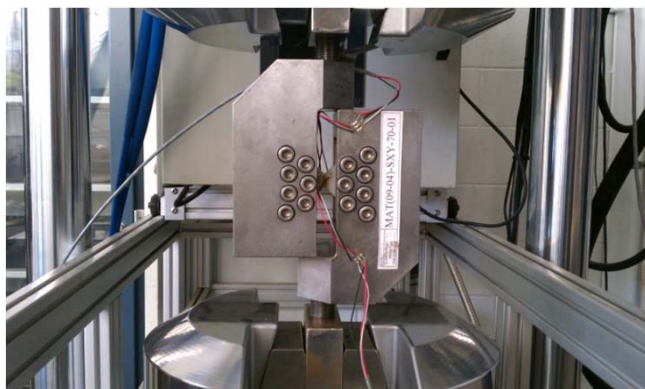
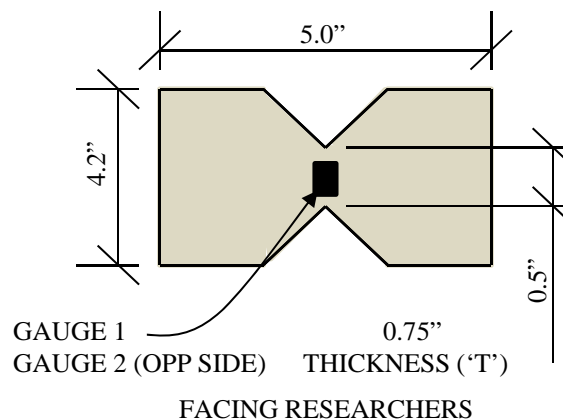
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXY-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **8,484** **lbs**
 Shear Strength, S_{xy} : **19,104** **psi**
 Shear Modulus, G_{xy} : **1,262,899** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT2-SXY-01-70-FY09 | 8,749 | 19,347 | 1,192,581 | Shear |
| 2 | MAT2-SXY-02-70-FY09 | 8,443 | 18,680 | 1,288,668 | Shear |
| 3 | MAT2-SXY-03-70-FY09 | 9,040 | 20,407 | 1,437,161 | Shear |
| 4 | MAT2-SXY-04-70-FY09 | 8,666 | 19,344 | 1,184,476 | Shear |
| 5 | MAT2-SXY-05-70-FY09 | 7,522 | 17,741 | 1,211,610 | Shear |
| Average | | 8,484 | 19,104 | 1,262,899 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets E-44 to E-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-70-FY09
 Test Date: 7/22/2011
 Specimen Received: 5/20/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 8,749 lbs
 Shear Strength, S_{xy} : 19,347 psi
 Shear Modulus, G_{xy} : 1,192,581 psi

Measured Specimen Dimensions:

Thickness, T: 0.760 in
 Notch Length, N: 0.595 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,750 lbs
 50% Max Load: 4,374 lbs

PICTURE OF SPECIMEN PRE-TEST



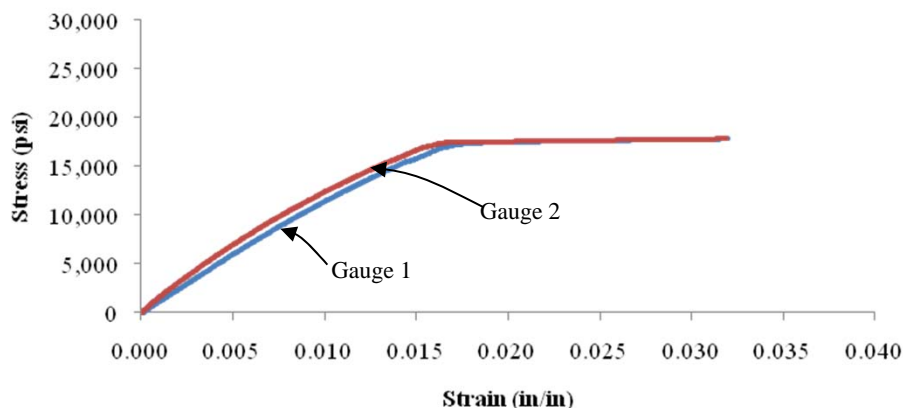
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00828 | 0.00325 | 1,154,630 |
| 2 | 0.00731 | 0.00260 | 1,230,531 |
| Average | | | 1,192,581 |

Stress-Strain Curve 70F_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-70-FY09
 Test Date: 7/25/2011
 Specimen Received: 5/20/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 8,443 lbs
 Shear Strength, S_{xy} : 18,680 psi
 Shear Modulus, G_{xy} : 1,288,668 psi

Measured Specimen Dimensions:

Thickness, T: 0.740 in
 Notch Length, N: 0.598 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,689 lbs
 50% Max Load: 4,222 lbs

PICTURE OF SPECIMEN PRE-TEST



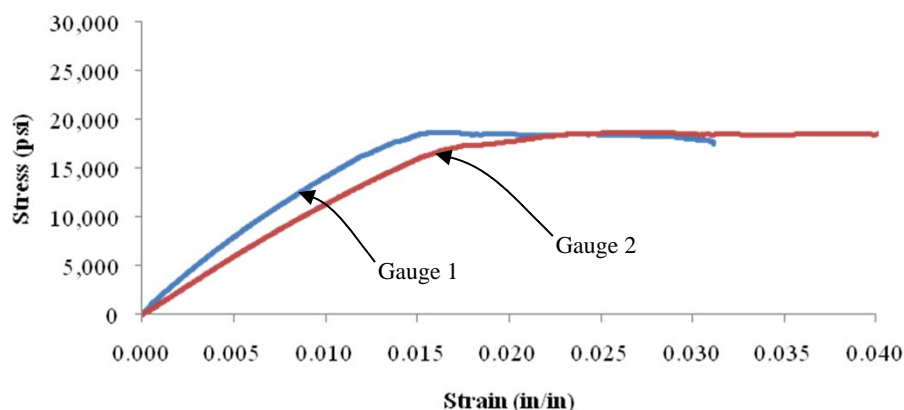
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00600 | 0.00211 | 1,439,969 |
| 2 | 0.00804 | 0.00311 | 1,137,367 |
| Average | | | 1,288,668 |

Stress-Strain Curve 70F_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-70-FY09
 Test Date: 7/25/2011
 Specimen Received: 5/20/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,040 lbs
 Shear Strength, S_{xy} : 20,407 psi
 Shear Modulus, G_{xy} : 1,437,161 psi

Measured Specimen Dimensions:

Thickness, T: 0.740 in
 Notch Length, N: 0.618 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,808 lbs
 50% Max Load: 4,520 lbs

PICTURE OF SPECIMEN PRE-TEST



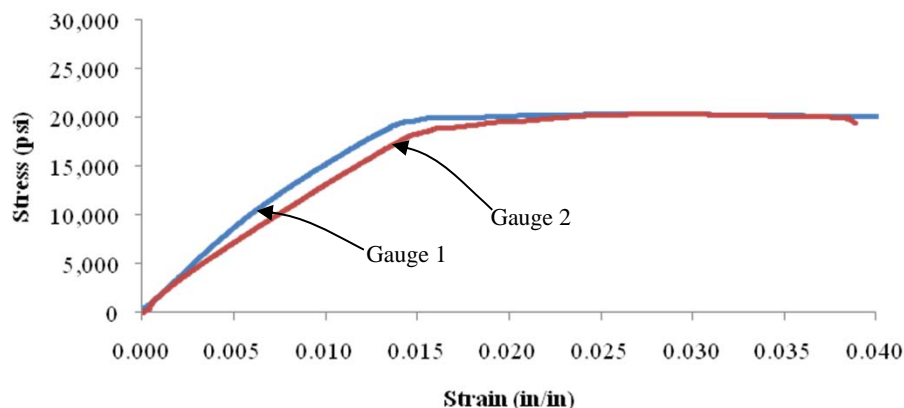
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00598 | 0.00225 | 1,641,228 |
| 2 | 0.00751 | 0.00254 | 1,233,095 |
| Average | | | 1,437,161 |

Stress-Strain Curve 70F_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-70-FY09
 Test Date: 7/25/2011
 Specimen Received: 5/20/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 8,666 lbs
 Shear Strength, S_{xy} : 19,344 psi
 Shear Modulus, G_{xy} : 1,184,476 psi

Measured Specimen Dimensions:

Thickness, T: 0.749 in
 Notch Length, N: 0.598 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,733 lbs
 50% Max Load: 4,333 lbs

PICTURE OF SPECIMEN PRE-TEST



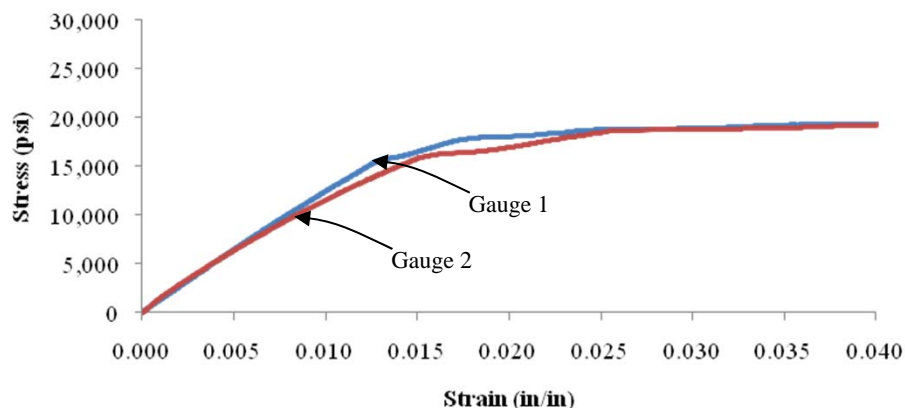
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00756 | 0.00295 | 1,256,894 |
| 2 | 0.00804 | 0.00804 | 1,112,059 |
| Average | | | 1,184,476 |

Stress-Strain Curve 70F_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-70-FY09
 Test Date: 7/25/2011
 Specimen Received: 5/20/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,522 lbs
 Shear Strength, S_{xy} : 17,741 psi
 Shear Modulus, G_{xy} : 1,403,373 psi

Measured Specimen Dimensions:

Thickness, T: 0.759 in
 Notch Length, N: 0.558 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,504 lbs
 50% Max Load: 3,761 lbs

PICTURE OF SPECIMEN PRE-TEST



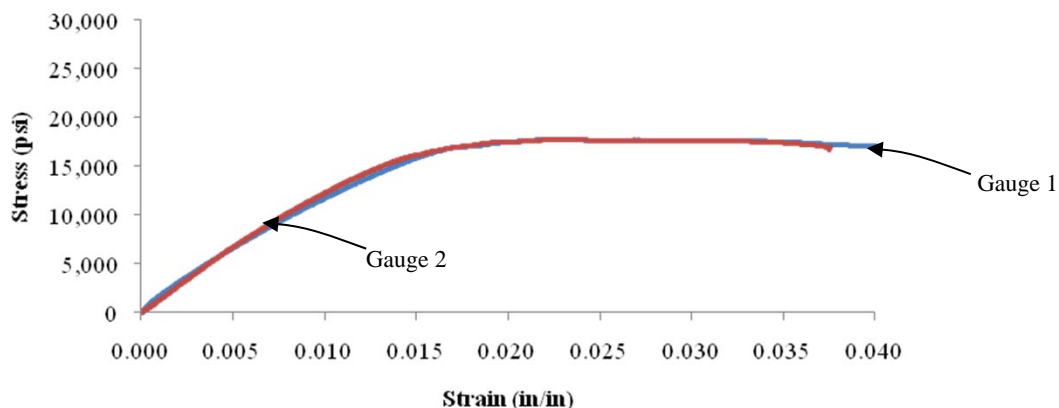
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00704 | 0.00238 | 1,141,098 |
| 2 | 0.00676 | 0.00261 | 1,282,121 |
| Average | | | 1,211,610 |

Stress-Strain Curve 70F_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

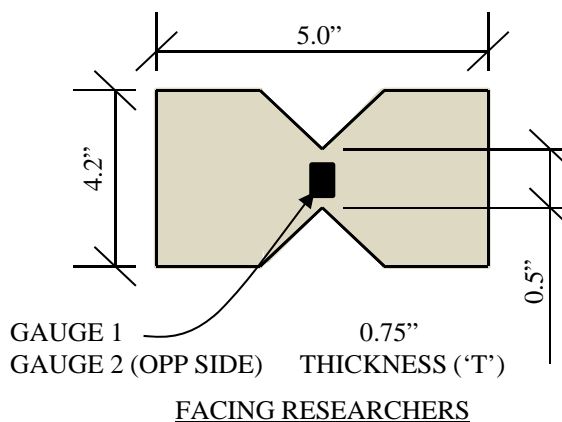
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXY-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **4,386** **lbs**
 Shear Strength, S_{xy} : **10,301** **psi**
 Shear Modulus, G_{xy} : **910,531** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT2-SXY-01-140-FY09 | 4,601 | 10,955 | 1,047,527 | Shear |
| 2 | MAT2-SXY-02-140-FY09 | 4,015 | 9,560 | 775,068 | Shear |
| 3 | MAT2-SXY-03-140-FY09 | 4,389 | 10,044 | 891,321 | Shear |
| 4 | MAT2-SXY-04-140-FY09 | 4,607 | 10,738 | 977,797 | Shear |
| 5 | MAT2-SXY-05-140-FY09 | 4,318 | 10,208 | 860,943 | Shear |
| Average | | 4,386 | 10,301 | 910,531 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets E-50 to E-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-01-140-FY09
 Test Date: 7/26/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,601 lbs
 Shear Strength, S_{xy} : 10,955 psi
 Shear Modulus, G_{xy} : 1,047,527 psi

Measured Specimen Dimensions:

Thickness, T: 0.765 in
 Notch Length, N: 0.549 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 920 lbs
 50% Max Load: 2,301 lbs

PICTURE OF SPECIMEN PRE-TEST



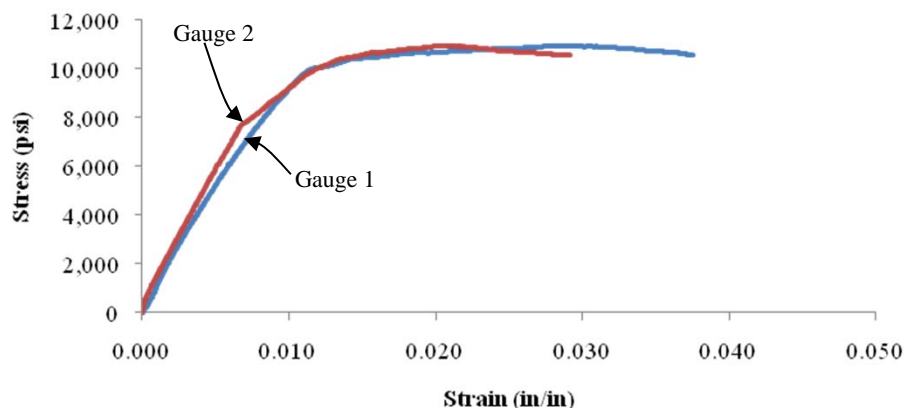
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00523 | 0.00191 | 990,912 |
| 2 | 0.00457 | 0.00159 | 1,104,142 |
| Average | | | 1,047,527 |

Stress-Strain Curve 140F_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-02-140-FY09
 Test Date: 7/26/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,015 lbs
 Shear Strength, S_{xy} : 9,560 psi
 Shear Modulus, G_{xy} : 775,068 psi

Measured Specimen Dimensions:

Thickness, T: 0.760 in
 Notch Length, N: 0.553 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 803 lbs
 50% Max Load: 2,008 lbs

PICTURE OF SPECIMEN PRE-TEST



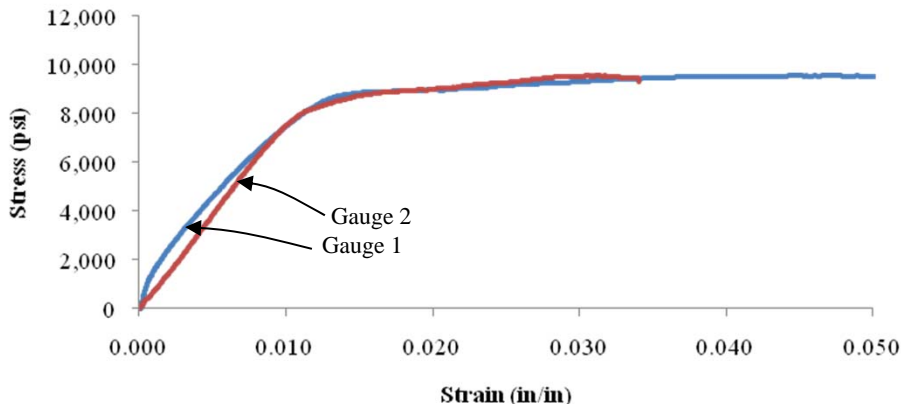
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00527 | 0.00137 | 736,892 |
| 2 | 0.00614 | 0.00262 | 813,154 |
| Average | | | 775,068 |

Stress-Strain Curve 140F_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-03-140-FY09
 Test Date: 7/26/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,389 lbs
 Shear Strength, S_{xy} : 10,044 psi
 Shear Modulus, G_{xy} : 891,321 psi

Measured Specimen Dimensions:

Thickness, T : 0.755 in
 Notch Length, N : 0.579 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 878 lbs
 50% Max Load: 2,195 lbs

PICTURE OF SPECIMEN PRE-TEST



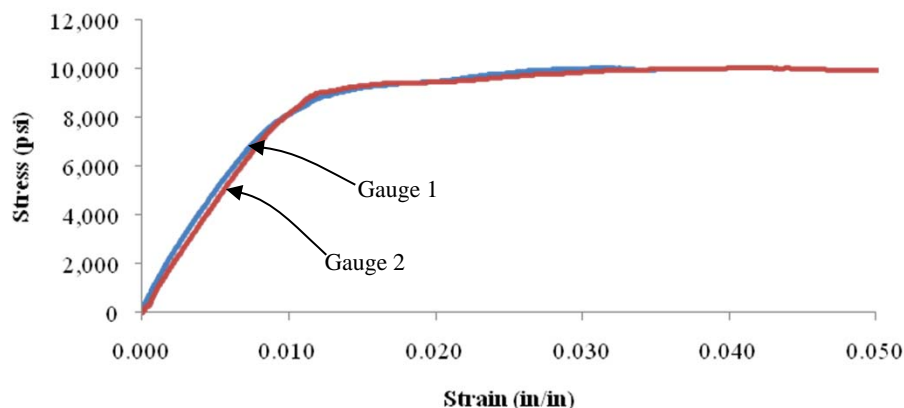
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00498 | 0.00165 | 904,943 |
| 2 | 0.00553 | 0.00210 | 877,700 |
| Average | | | 891,321 |

Stress-Strain Curve 140F_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-04-140-FY09
 Test Date: 7/27/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,607 lbs
 Shear Strength, S_{xy} : 10,738 psi
 Shear Modulus, G_{xy} : 977,797 psi

Measured Specimen Dimensions:

Thickness, T: 0.745 in
 Notch Length, N: 0.575 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 921 lbs
 50% Max Load: 2,303 lbs

PICTURE OF SPECIMEN PRE-TEST



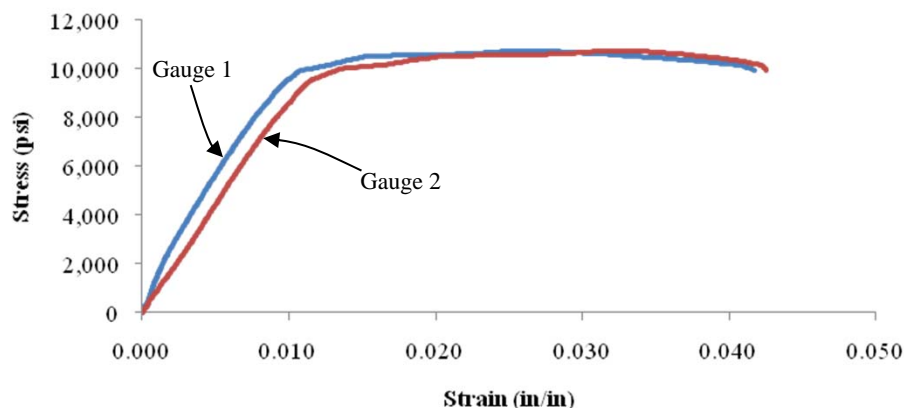
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00464 | 0.00150 | 1,025,922 |
| 2 | 0.00595 | 0.00249 | 929,672 |
| Average | | | 977,797 |

Stress-Strain Curve 140F_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT2-SXY-05-140-FY09
 Test Date: 7/27/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,318 lbs
 Shear Strength, S_{xy} : 10,208 psi
 Shear Modulus, G_{xy} : 860,943 psi

Measured Specimen Dimensions:

Thickness, T: 0.760 in
 Notch Length, N: 0.556 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 864 lbs
 50% Max Load: 2,159 lbs

PICTURE OF SPECIMEN PRE-TEST



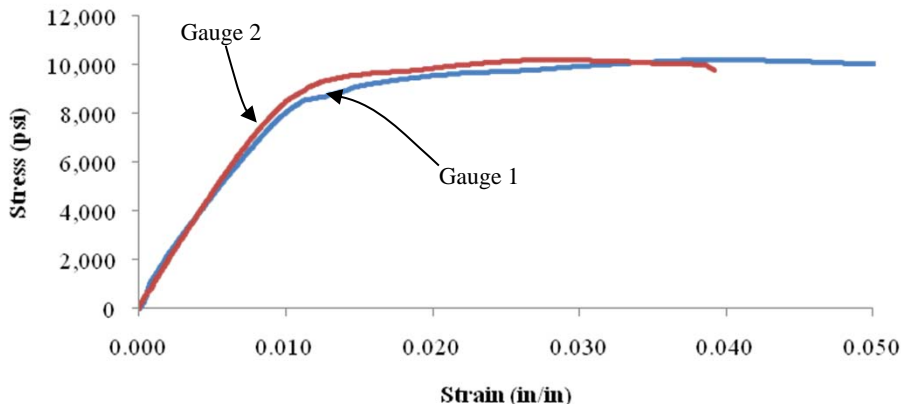
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00557 | 0.00178 | 806,355 |
| 2 | 0.00535 | 0.00201 | 915,530 |
| Average | | | 860,943 |

Stress-Strain Curve 140F_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TZ-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 1,729 lbs

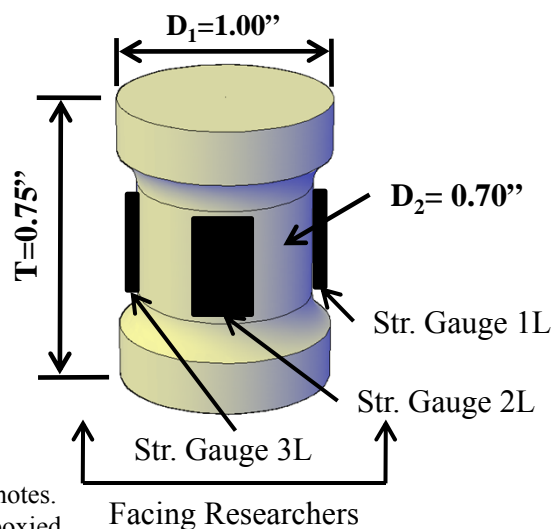
Tensile Strength, ST_z : 4,477 psi

Tensile Modulus, E_z : 1,121,661 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT2-TZ-1-N40-FY09 | 1,609 | 4,182 | 1,098,406 | Rupture |
| MAT2-TZ-2-N40-FY09 | 1,769 | 4,570 | 1,111,525 | Rupture |
| MAT2-TZ-3-N40-FY09 | 1,809 | 4,686 | 1,196,389 | Rupture |
| MAT2-TZ-4-N40-FY09 | 1,680 | 4,365 | 1,079,042 | Rupture |
| MAT2-TZ-5-N40-FY09 | 1,778 | 4,582 | 1,122,943 | Rupture |
| Average | 1,729 | 4,477 | 1,121,661 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-56 to E-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-1-N40-FY09**
 Test Date: 8/11/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,182 psi
 Tensile Modulus, E_z : 1,098,406 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.000 in
 Diameter, D_2 : 0.700 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 2,091 psi

20% Max Stress: 836 psi

PICTURE OF SPECIMEN PRE-TEST



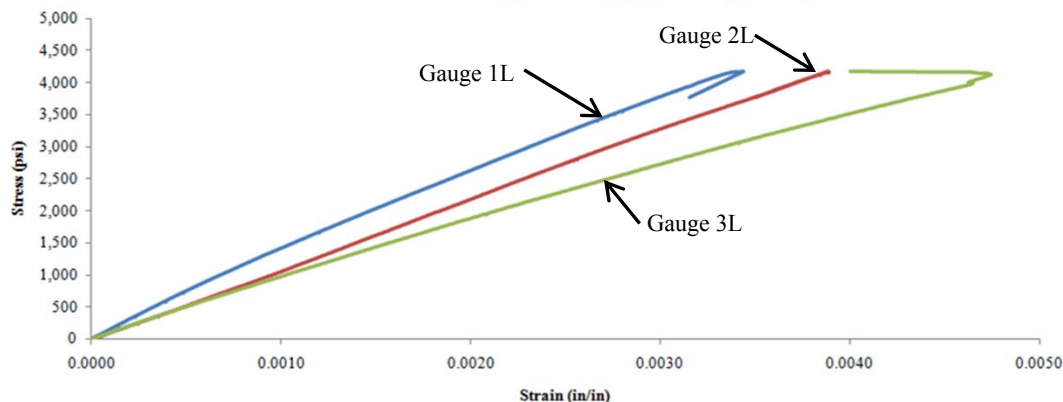
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001542 | 0.000557 | 1,273,558 |
| 2L | 0.001914 | 0.000793 | 1,118,717 |
| 3L | 0.002237 | 0.000848 | 902,942 |
| Average | | | 1,098,406 |

Stress-Strain Curve_N40°F_1_(09-02)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-N40-FY09**
 Test Date: 8/11/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,570 psi
 Tensile Modulus, E_z : 1,111,525 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.702 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 2,285 psi

20% Max Stress: 914 psi

PICTURE OF SPECIMEN PRE-TEST



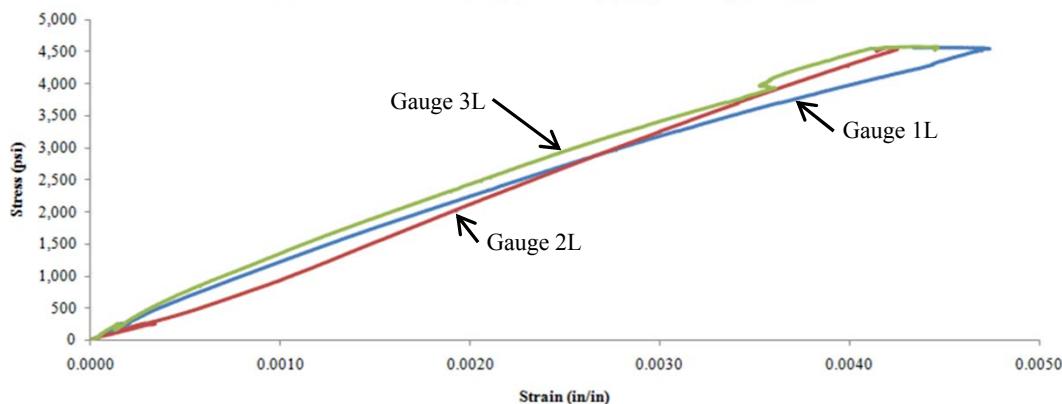
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002040 | 0.000718 | 1,036,901 |
| 2L | 0.002136 | 0.000978 | 1,183,827 |
| 3L | 0.001853 | 0.000622 | 1,113,848 |
| Average | | | 1,111,525 |

Stress-Strain Curve_N40°F_2_(09-02)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-N40-FY09**
 Test Date: 8/11/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,686 psi
 Tensile Modulus, E_z : 1,196,389 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.701 in

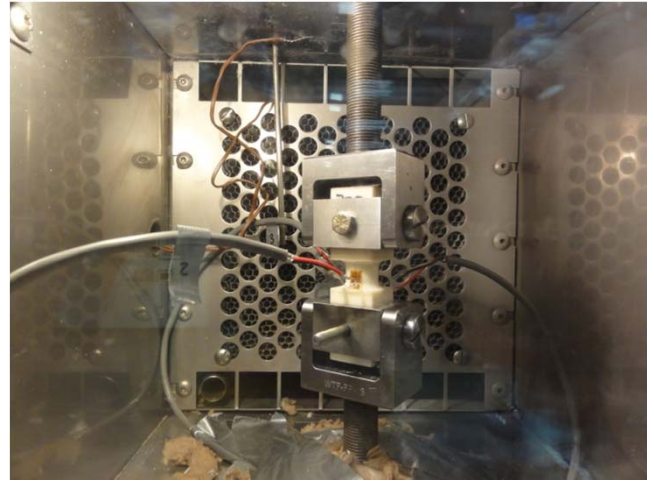
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 2,343 psi

20% Max Stress: 937 psi

PICTURE OF SPECIMEN PRE-TEST



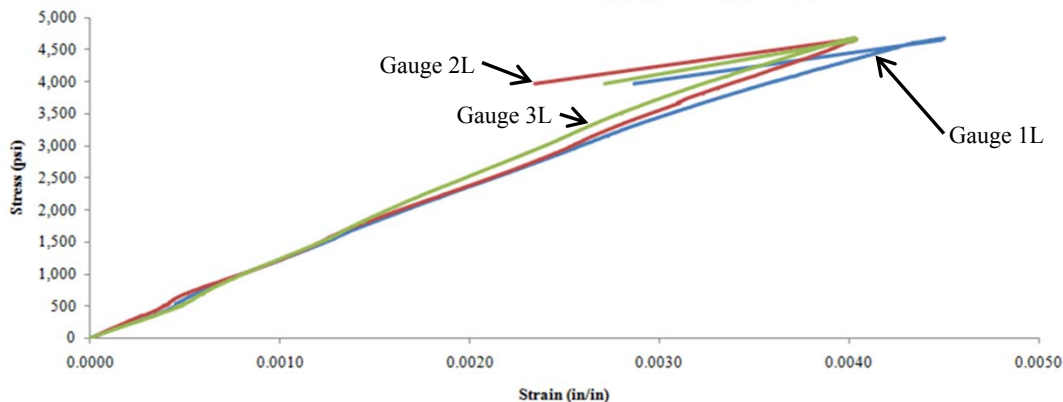
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001971 | 0.000745 | 1,146,432 |
| 2L | 0.001959 | 0.000729 | 1,143,302 |
| 3L | 0.001833 | 0.000752 | 1,299,432 |
| Average | | | 1,196,389 |

Stress-Strain Curve_N40°F_3_(09-02)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-N40-FY09**
 Test Date: 8/12/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,365 psi
 Tensile Modulus, E_z : 1,079,042 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.700 in

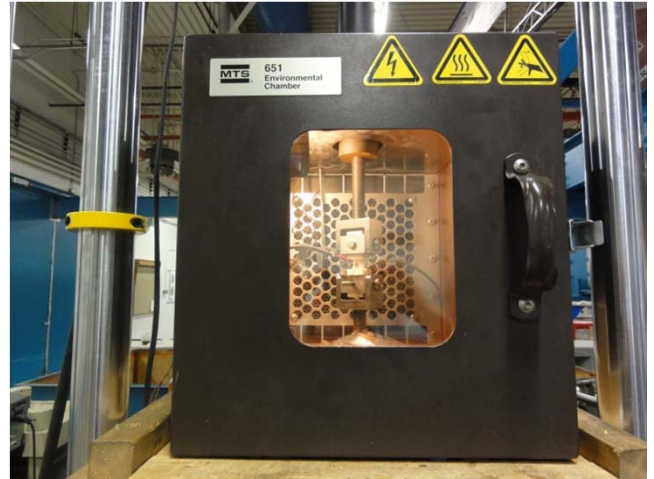
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 2,183 psi

20% Max Stress: 873 psi

PICTURE OF SPECIMEN PRE-TEST



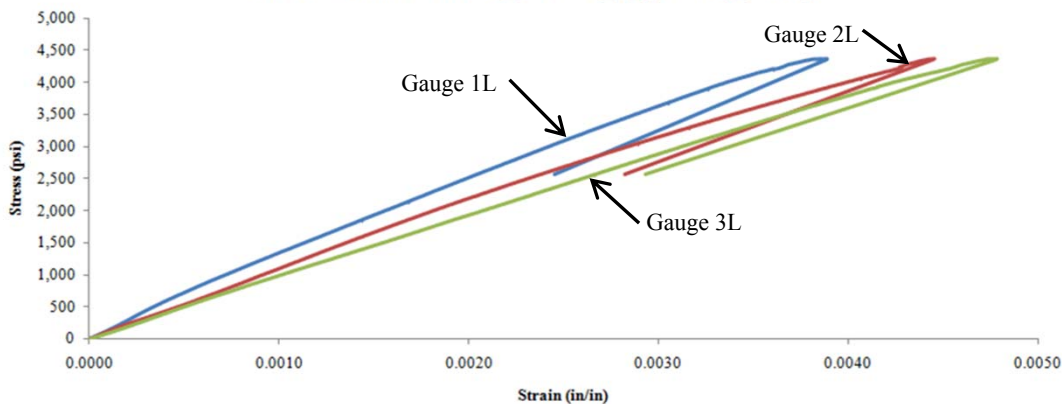
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001716 | 0.000616 | 1,190,662 |
| 2L | 0.001990 | 0.000803 | 1,103,721 |
| 3L | 0.002266 | 0.000876 | 942,743 |
| Average | | | 1,079,042 |

Stress-Strain Curve_N40°F_4_(09-02)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-N40-FY09**
 Test Date: 8/12/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,582 psi
 Tensile Modulus, E_z : 1,122,943 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.703 in

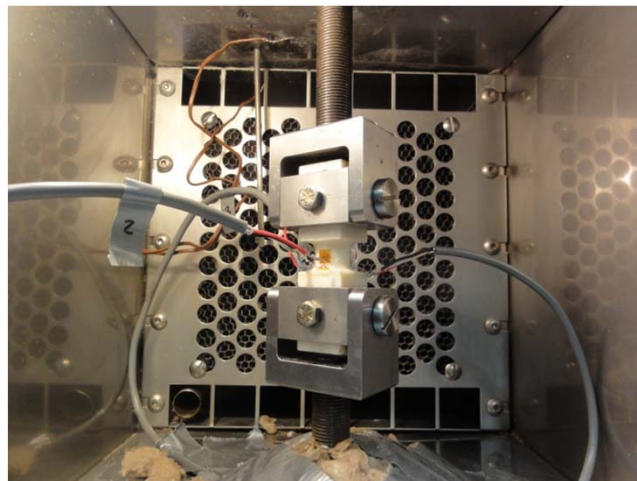
Laboratory Temperature: 68°F

Failure Mode: Rupture

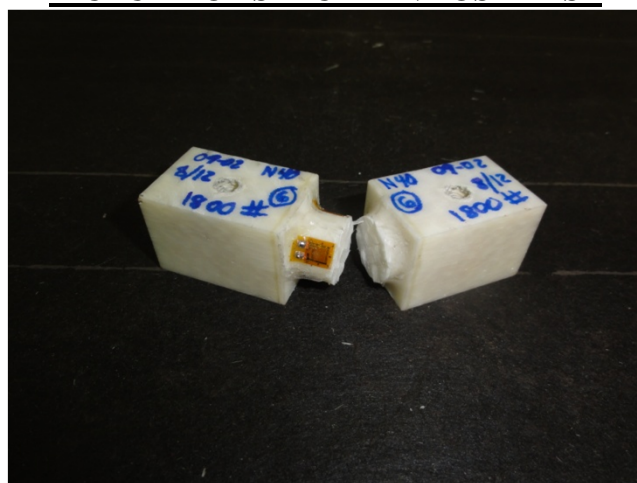
50% Max Stress: 2,291 psi

20% Max Stress: 916 psi

PICTURE OF SPECIMEN PRE-TEST



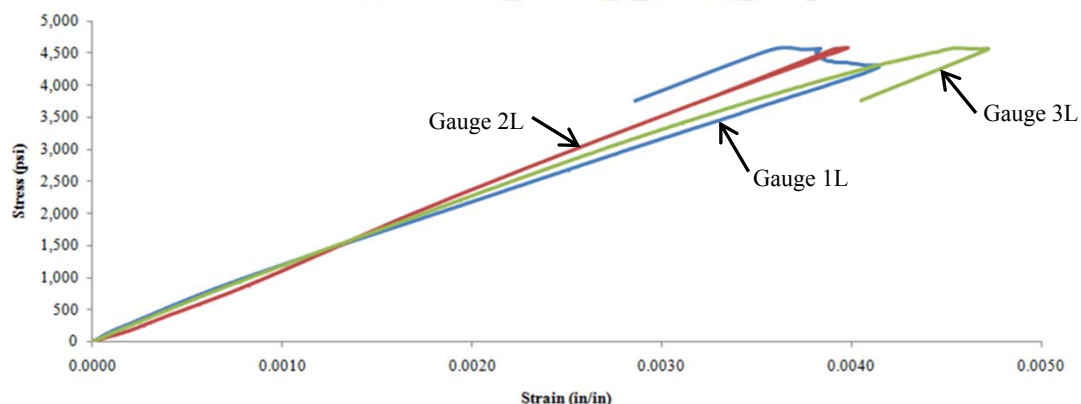
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002103 | 0.000726 | 998,156 |
| 2L | 0.001930 | 0.000851 | 1,273,523 |
| 3L | 0.002010 | 0.000757 | 1,097,151 |
| Average | | | 1,122,943 |

Stress-Strain Curve_N40°F_5_(09-02)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-TZ-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 70°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 1,256 lbs

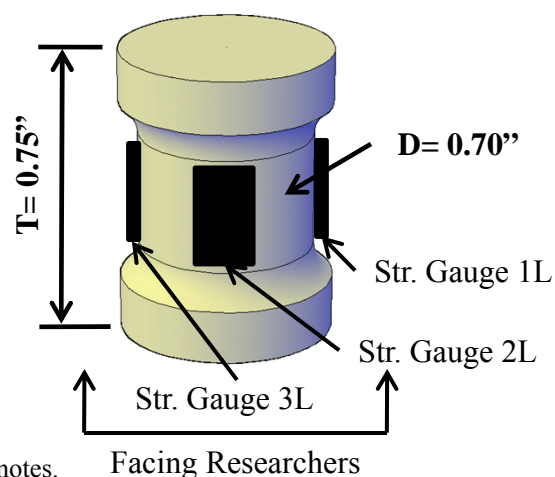
Tensile Strength, ST_z : 3,304 psi

Tensile Modulus, E_z : 985,645 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT2-TZ-1-70-FY09 | 1,339 | 3,509 | 1,001,530 | Rupture |
| MAT2-TZ-2-70-FY09 | 1,286 | 3,332 | 1,068,938 | Rupture |
| MAT2-TZ-3-70-FY09 | 1,343 | 3,421 | 950,824 | Rupture |
| MAT2-TZ-4-70-FY09 | 1,183 | 3,074 | 961,987 | Rupture |
| MAT2-TZ-5-70-FY09 | 1,129 | 3,184 | 944,946 | Rupture |
| Average | 1,256 | 3,304 | 985,645 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-62 to E-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-1-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,509 psi
 Tensile Modulus, E_z : 1,001,530 psi

Measured Specimen Dimensions:

Diameter, D: 0.697 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,754 psi
 20% Max Stress: 702 psi

PICTURE OF SPECIMEN PRE-TEST



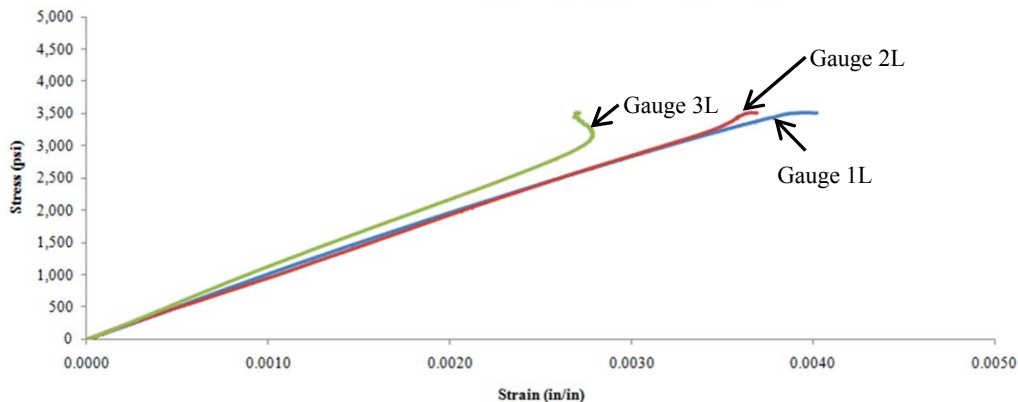
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001772 | 0.000686 | 969,512 |
| 2L | 0.001825 | 0.000729 | 960,796 |
| 3L | 0.001592 | 0.000612 | 1,074,282 |
| Average | | | 1,001,530 |

Stress-Strain Curve_70°F_1_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

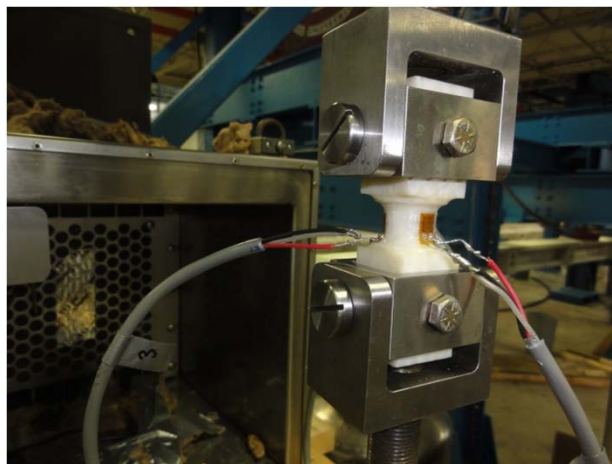
Average Material Properties:

Tensile Strength, ST_z : 3,332 psi
 Tensile Modulus, E_z : 1,068,938 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,666 psi
 20% Max Stress: 666 psi

PICTURE OF SPECIMEN PRE-TEST



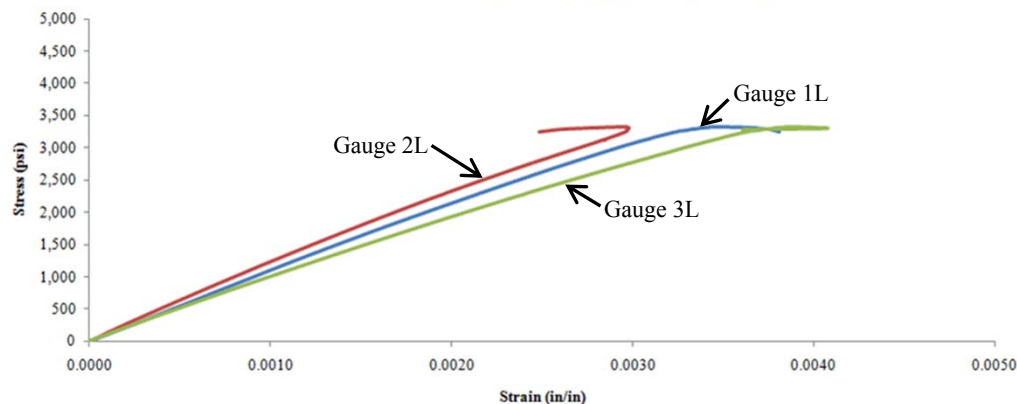
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001518 | 0.000602 | 1,090,367 |
| 2L | 0.001373 | 0.000517 | 1,168,251 |
| 3L | 0.001694 | 0.000640 | 948,196 |
| Average | | | 1,068,938 |

Stress-Strain Curve_70°F_2_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

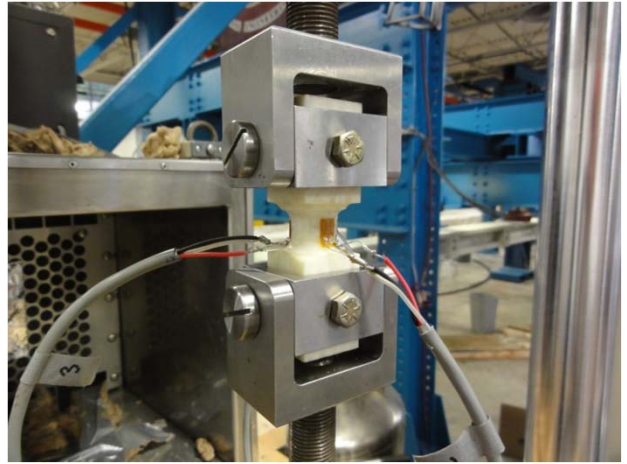
Average Material Properties:

Tensile Strength, ST_z : 3,421 psi
 Tensile Modulus, E_z : 950,824 psi

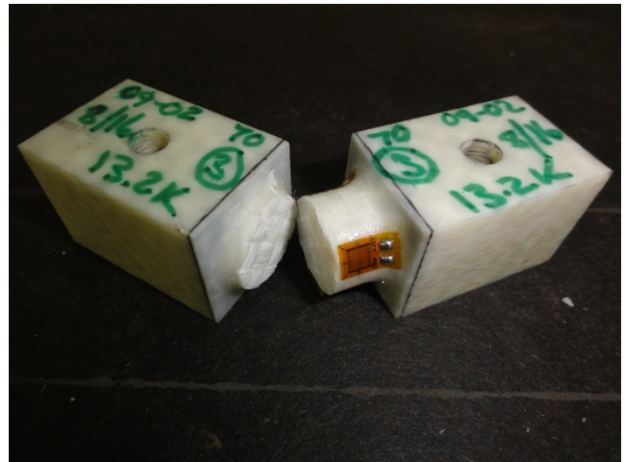
Measured Specimen Dimensions:

Diameter, D: 0.707 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,710 psi
 20% Max Stress: 684 psi

PICTURE OF SPECIMEN PRE-TEST



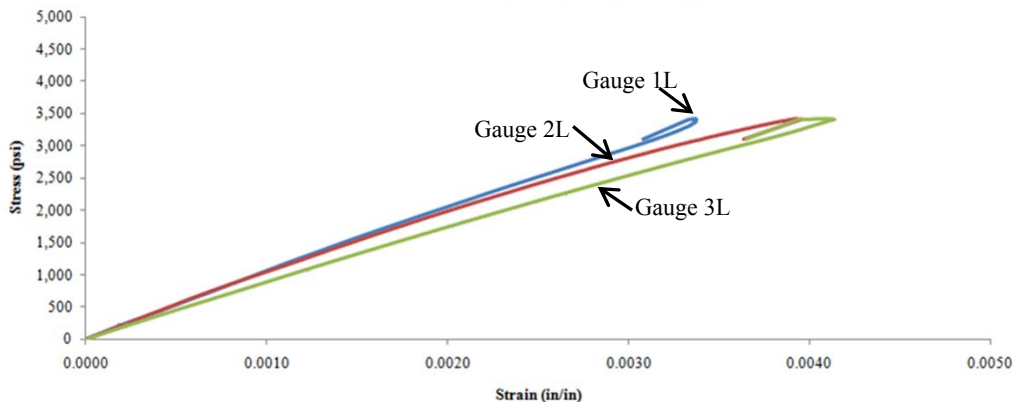
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001633 | 0.000638 | 1,032,145 |
| 2L | 0.001686 | 0.000621 | 964,189 |
| 3L | 0.001954 | 0.000755 | 856,137 |
| Average | | | 950,824 |

Stress-Strain Curve_70°F_3_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

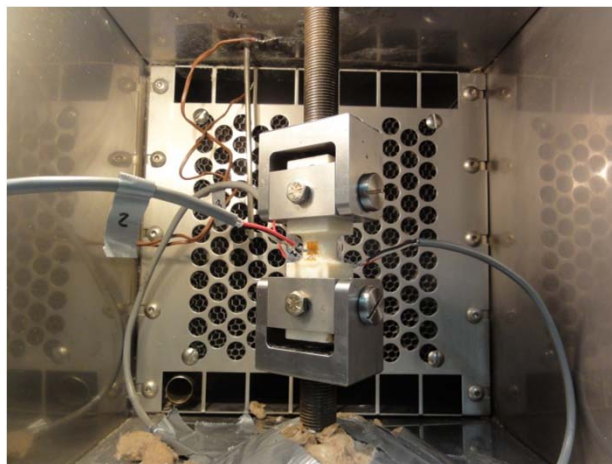
Average Material Properties:

Tensile Strength, ST_z : 3,074 psi
 Tensile Modulus, E_z : 961,987 psi

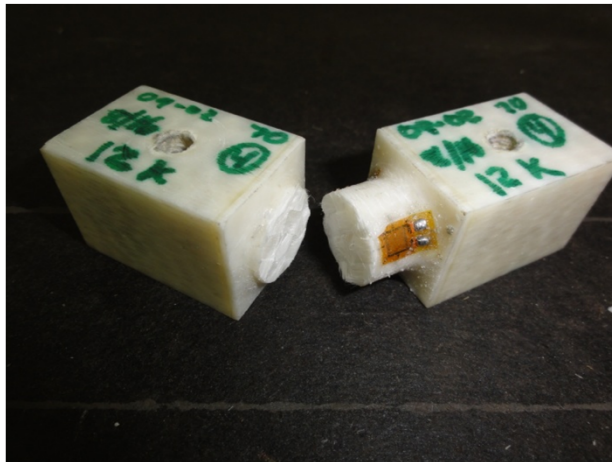
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,537 psi
 20% Max Stress: 615 psi

PICTURE OF SPECIMEN PRE-TEST



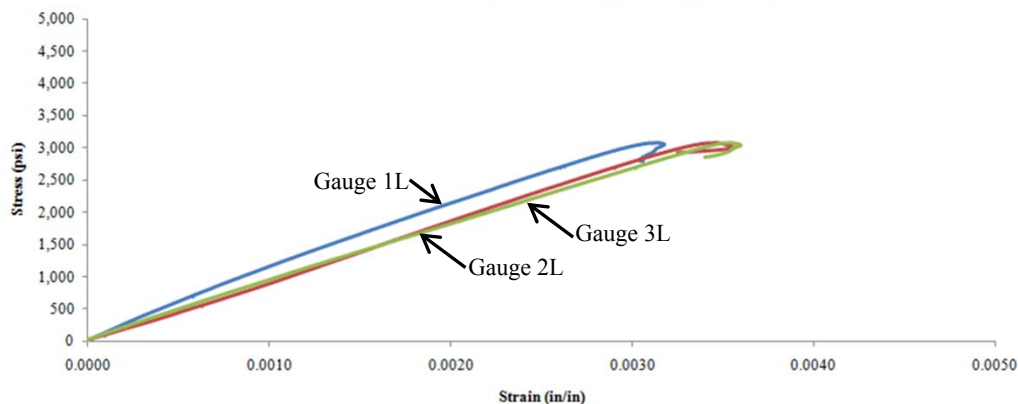
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001370 | 0.000492 | 1,050,855 |
| 2L | 0.001657 | 0.000689 | 952,451 |
| 3L | 0.001663 | 0.000619 | 882,655 |
| Average | | | 961,987 |

Stress-Strain Curve_70°F_4_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-70-FY09**
 Test Date: 8/17/2011
 Specimen Received: 5/20/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,184 psi
 Tensile Modulus, E_z : 944,946 psi

Measured Specimen Dimensions:

Diameter, D: 0.672 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,592 psi
 20% Max Stress: 637 psi

PICTURE OF SPECIMEN PRE-TEST



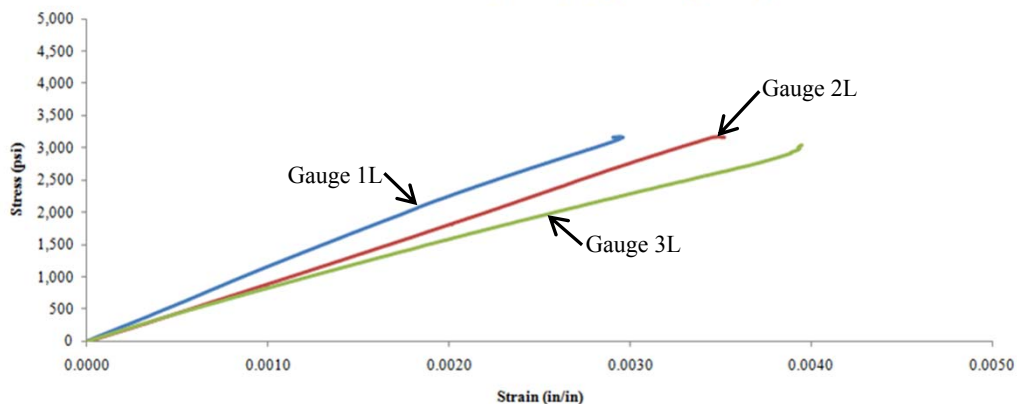
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001379 | 0.000549 | 1,151,792 |
| 2L | 0.001757 | 0.000718 | 919,102 |
| 3L | 0.002002 | 0.000752 | 763,944 |
| Average | | | 944,946 |

Stress-Strain Curve_70°F_5_(09-02)_Long



Engineering Test notes:

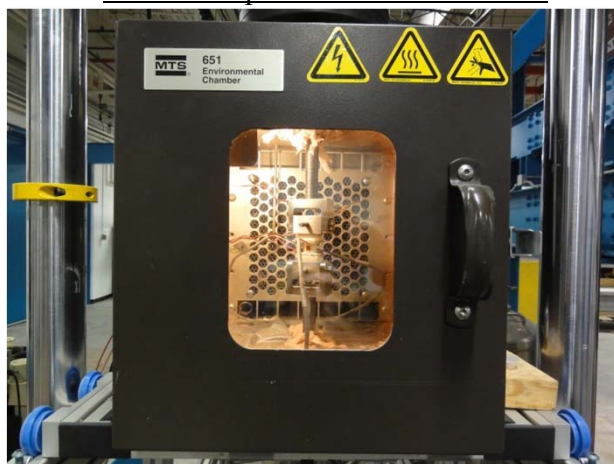
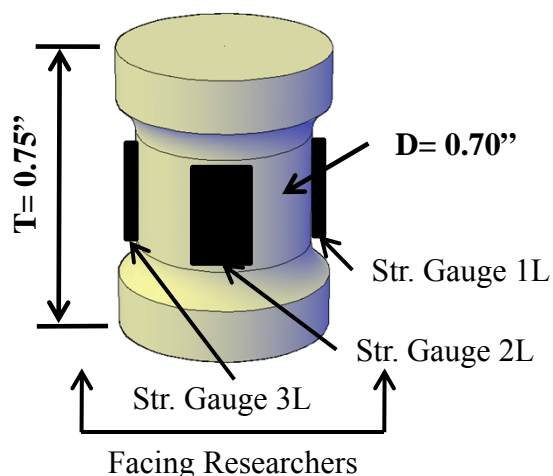
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT2-TZ-140-FY09**Material:** Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**Nominal Temperature:** 140°F**Properties Measured:** ST_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 607 lbs**Tensile Strength, ST_z :** 1,602 psi**Tensile Modulus, E_z :** 264,627 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT2-TZ-1-140-FY09 | 600 | 1,591 | 297,402 | Rupture |
| MAT2-TZ-2-140-FY09 | 657 | 1,743 | 298,827 | Rupture |
| MAT2-TZ-3-140-FY09 | 652 | 1,718 | 310,381 | Rupture |
| MAT2-TZ-4-140-FY09 | 547 | 1,451 | 209,610 | Rupture |
| MAT2-TZ-5-140-FY09 | 578 | 1,506 | 206,915 | Rupture |
| Average | 607 | 1,602 | 264,627 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-68 to E-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: MAT2-TZ-1-140-FY09
 Test Date: 2/24/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,591 psi
 Tensile Modulus, E_z : 297,402 psi

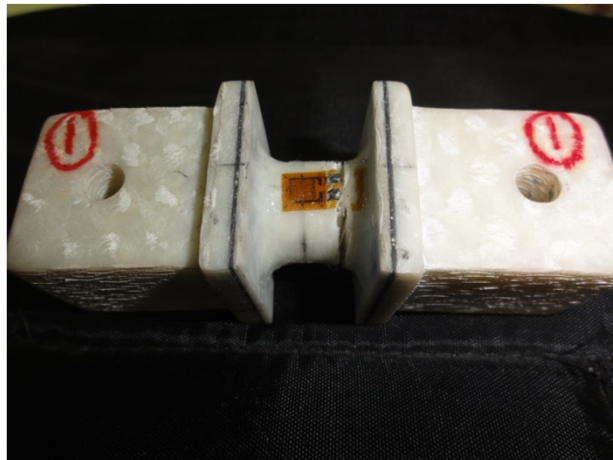
Measured Specimen Dimensions:

Diameter, D: 0.693 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 796 psi
 20% Max Stress: 318 psi

PICTURE OF SPECIMEN PRE-TEST



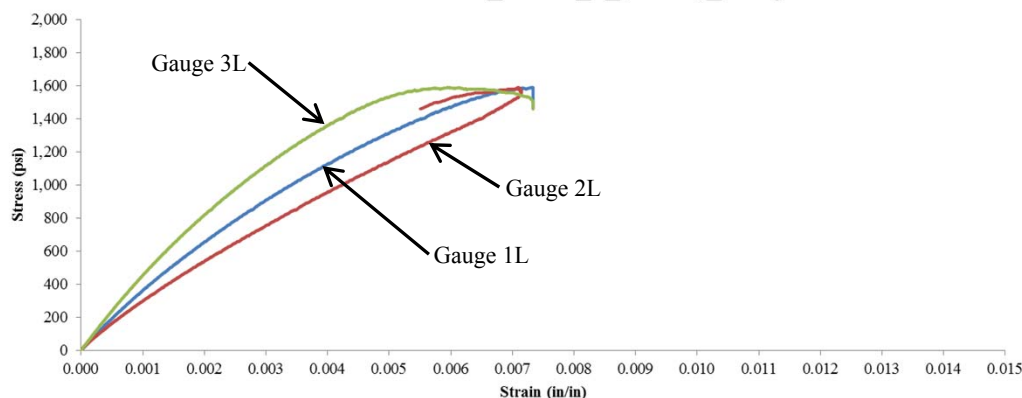
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002545 | 0.000873 | 285,589 |
| 2L | 0.003209 | 0.001088 | 225,065 |
| 3L | 0.001935 | 0.000684 | 381,552 |
| Average | | | 297,402 |

Stress-Strain Curve_140°F_1_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-2-140-FY09**
 Test Date: 2/24/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,743 psi
 Tensile Modulus, E_z : 298,827 psi

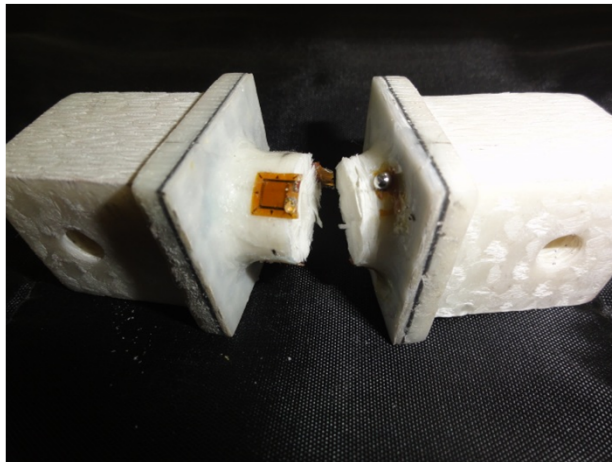
Measured Specimen Dimensions:

Diameter, D: 0.693 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 872 psi
 20% Max Stress: 349 psi

PICTURE OF SPECIMEN PRE-TEST



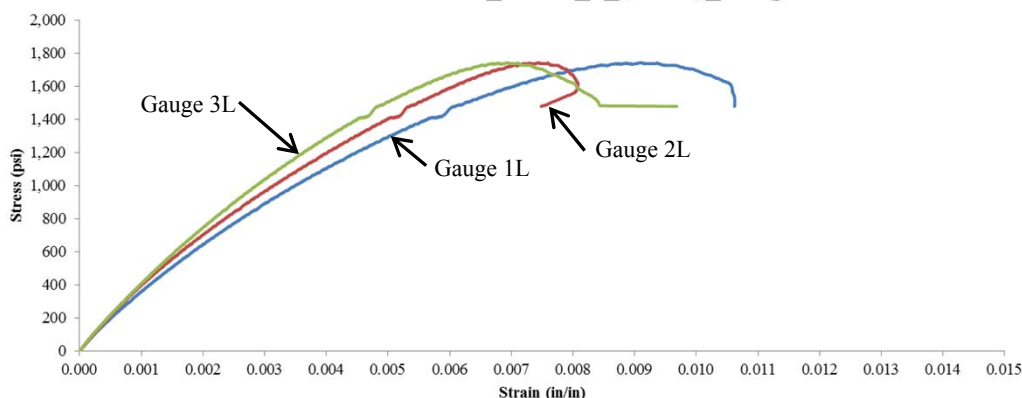
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002916 | 0.000965 | 268,054 |
| 2L | 0.002626 | 0.000859 | 295,973 |
| 3L | 0.002411 | 0.000838 | 332,454 |
| Average | | | 298,827 |

Stress-Strain Curve_140°F_2_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-3-140-FY09**
 Test Date: 2/27/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

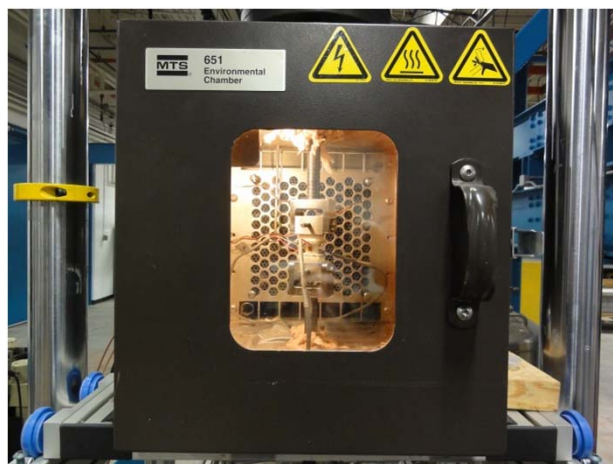
Average Material Properties:

Tensile Strength, ST_z : 1,718 psi
 Tensile Modulus, E_z : 310,381 psi

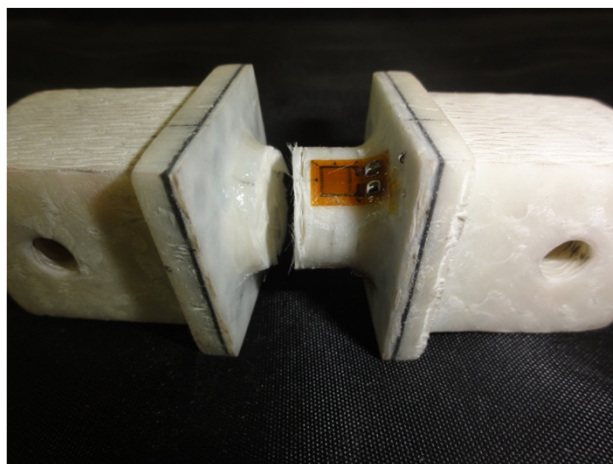
Measured Specimen Dimensions:

Diameter, D: 0.695 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 859 psi
 20% Max Stress: 344 psi

PICTURE OF SPECIMEN PRE-TEST



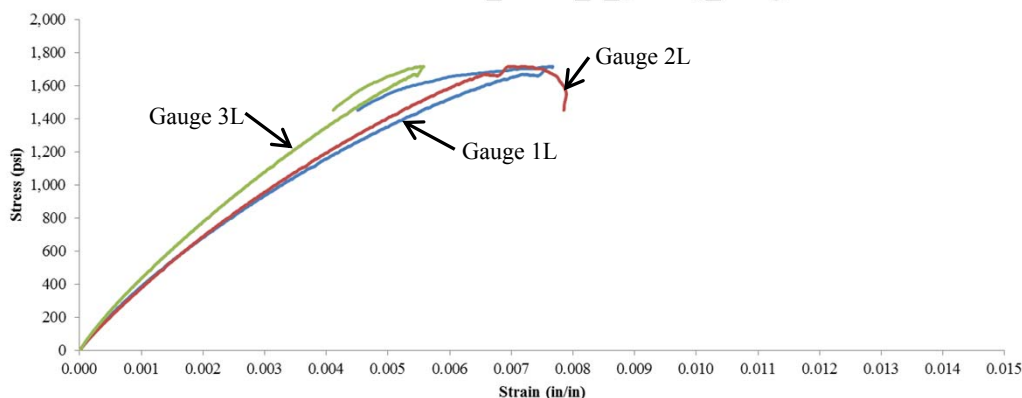
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002673 | 0.000870 | 285,833 |
| 2L | 0.002611 | 0.000900 | 301,318 |
| 3L | 0.002254 | 0.000755 | 343,991 |
| Average | | | 310,381 |

Stress-Strain Curve_140°F_3_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-4-140-FY09**
 Test Date: 2/27/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,451 psi
 Tensile Modulus, E_z : 209,610 psi

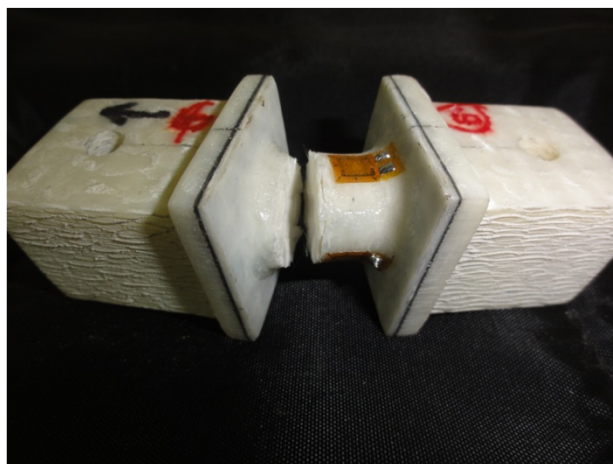
Measured Specimen Dimensions:

Diameter, D: 0.693 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 725 psi
 20% Max Stress: 290 psi

PICTURE OF SPECIMEN PRE-TEST



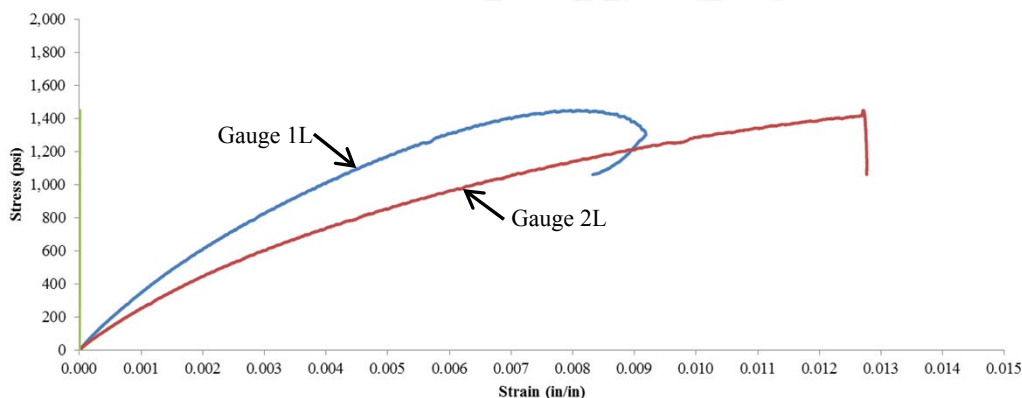
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002500 | 0.000814 | 258,104 |
| 2L | 0.003887 | 0.001186 | 161,117 |
| 3L | 0.000001 | 0.000000 | Lost Gauge |
| Average | | | 209,610 |

Stress-Strain Curve_140°F_4_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-TZ-5-140-FY09**
 Test Date: 3/28/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,506 psi
 Tensile Modulus, E_z : 206,915 psi

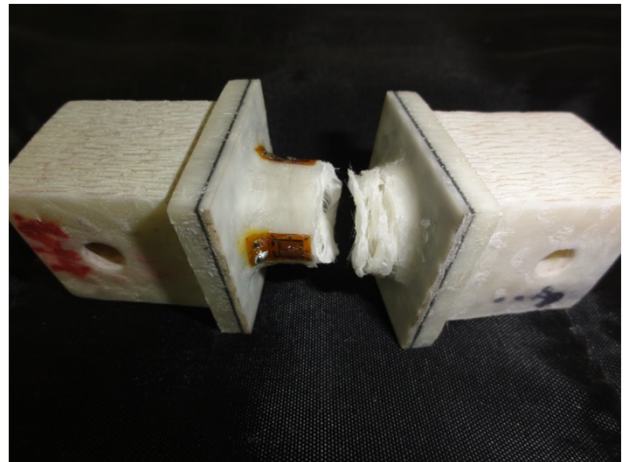
Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 753 psi
 20% Max Stress: 301 psi

PICTURE OF SPECIMEN PRE-TEST



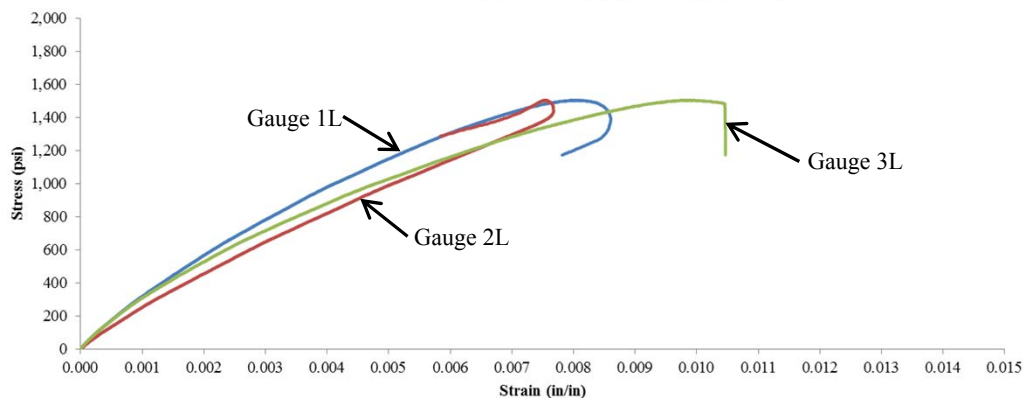
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002863 | 0.000922 | 232,762 |
| 2L | 0.003607 | 0.001211 | 188,532 |
| 3L | 0.003222 | 0.000957 | 199,451 |
| Average | | | 206,915 |

Stress-Strain Curve_140°F_5_(09-02)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CZ-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 39,125 lbs

Compressive Strength, SC_z : 69,614 psi

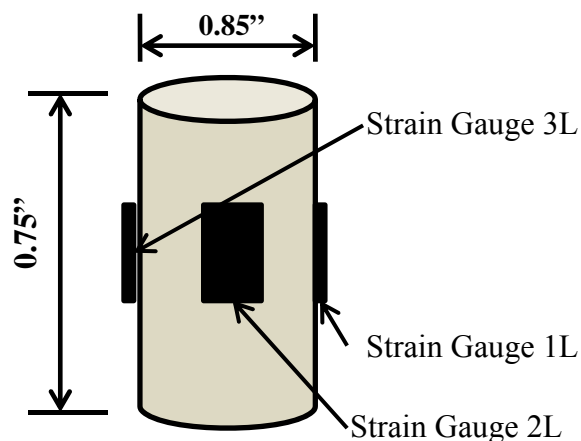
Compressive Modulus, E_z : 1,107,758 psi

Ultimate Strain, ϵ_z : 0.065 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT2-CZ-01-70-FY09 | 36,210 | 64,569 | 1,040,136 | 0.0623 | Rupture |
| MAT2-CZ-02-70-FY09 | 36,023 | 63,782 | 1,047,762 | 0.0640 | Rupture |
| MAT2-CZ-03-70-FY09 | 42,145 | 75,331 | 1,162,690 | 0.0658 | Rupture |
| MAT2-CZ-04-70-FY09 | 39,252 | 69,499 | 1,280,838 | 0.0549 | Rupture |
| MAT2-CZ-05-70-FY09 | 41,997 | 74,888 | 1,007,361 | 0.0759 | Rupture |
| Average | 39,125 | 69,614 | 1,107,758 | 0.065 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-74 to E-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-N40-FY09**
 Test Date: 5/24/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

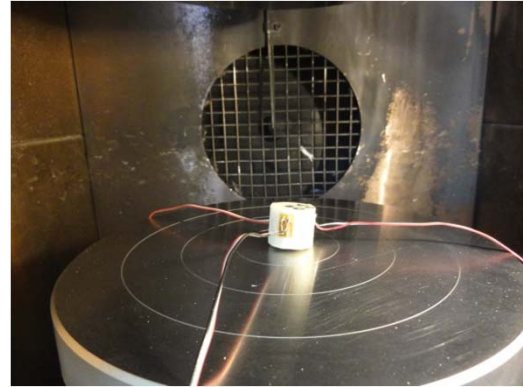
Average Material Properties:

Maximum Load, P_z : 36,210 lbs
 Compressive Strength, SC_z : 64,569 psi
 Compressive Modulus, E_z : 1,040,136 psi
 Ultimate Strain, ϵ_z : 0.062 in/in

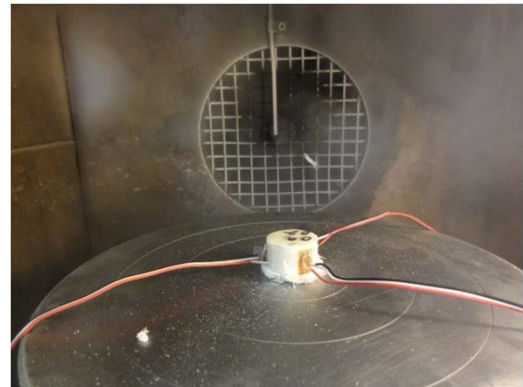
Measured Specimen Dimensions:

Thickness, T: 0.730 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,242 psi
 50% Max Load: 18,105 psi

PICTURE OF SPECIMEN PRE-TEST



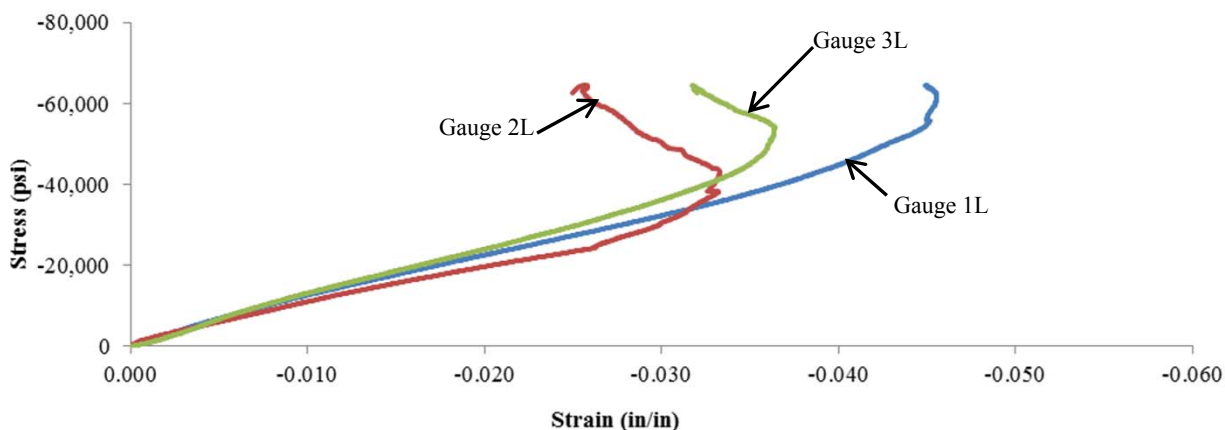
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02998 | 0.01026 | 982,546 |
| 2L | 0.03100 | 0.01196 | 1,017,304 |
| 3L | 0.02707 | 0.00978 | 1,120,559 |
| Average | | | 1,040,136 |

Stress-Strain Curve (09-02)_-40°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-N40-FY09**
 Test Date: 5/24/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

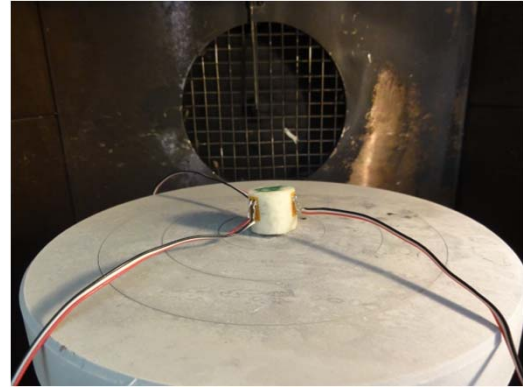
Average Material Properties:

Maximum Load, P_z : 36,023 lbs
 Compressive Strength, SC_z : 63,782 psi
 Compressive Modulus, E_z : 1,047,762 psi
 Ultimate Strain, ϵ_z : 0.064 in/in

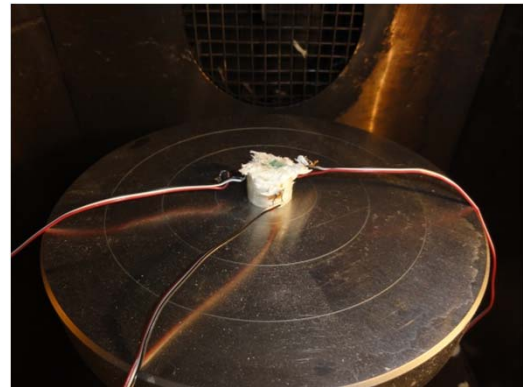
Measured Specimen Dimensions:

Thickness, T: 0.723 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,205 psi
 50% Max Load: 18,012 psi

PICTURE OF SPECIMEN PRE-TEST



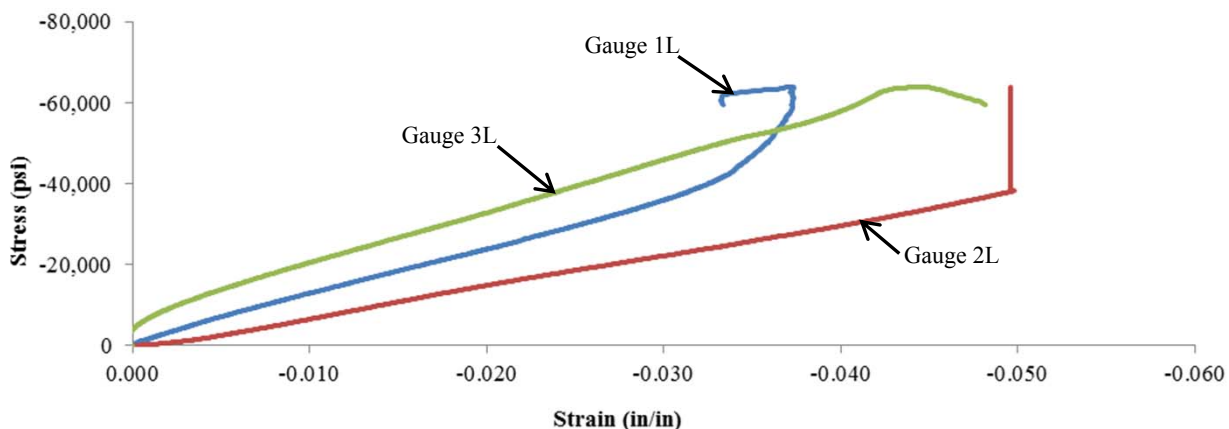
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02690 | 0.00983 | 1,120,565 |
| 2L | 0.04284 | 0.01731 | 749,632 |
| 3L | 0.01928 | 0.00425 | 1,273,091 |
| Average | | | 1,047,762 |

Stress-Strain Curve (09-02)_-40°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-N40-FY09**
 Test Date: 6/14/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

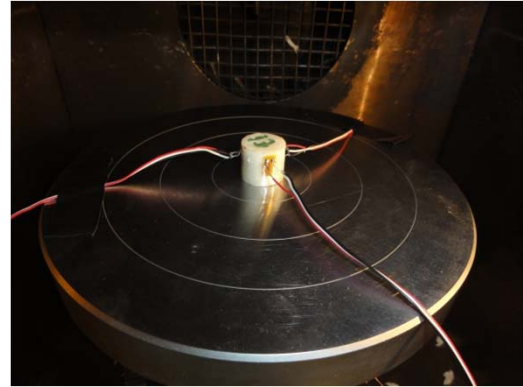
Average Material Properties:

Maximum Load, P_z : 42,145 lbs
 Compressive Strength, SC_z : 75,331 psi
 Compressive Modulus, E_z : 1,162,690 psi
 Ultimate Strain, ϵ_z : 0.066 in/in

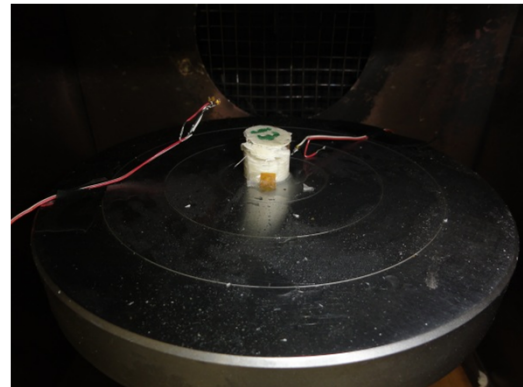
Measured Specimen Dimensions:

Thickness, T: 0.728 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,429 psi
 50% Max Load: 21,073 psi

PICTURE OF SPECIMEN PRE-TEST



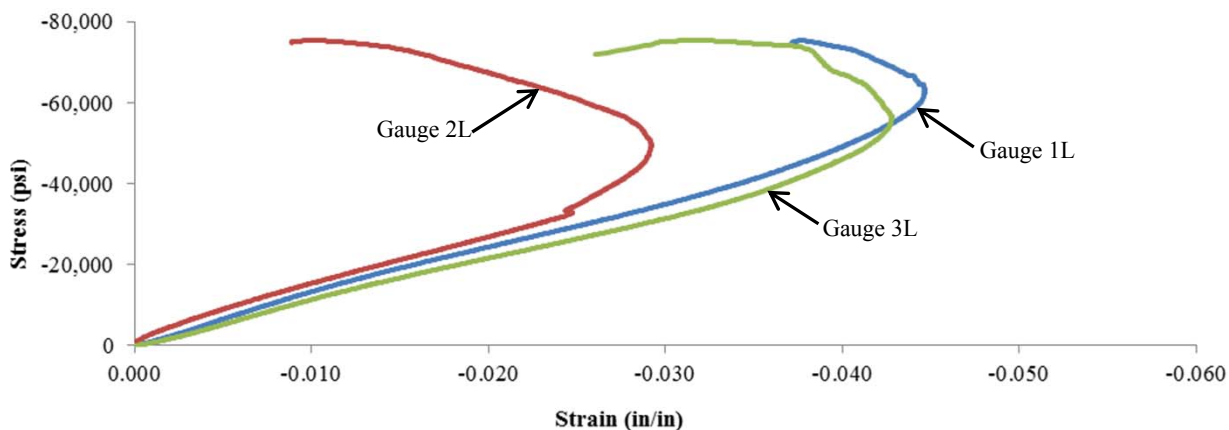
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03229 | 0.01141 | 1,082,440 |
| 2L | 0.02622 | 0.00973 | 1,369,903 |
| 3L | 0.03517 | 0.01335 | 1,035,728 |
| Average | | | 1,162,690 |

Stress-Strain Curve (09-02)_-40°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-N40-FY09**
 Test Date: 6/15/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

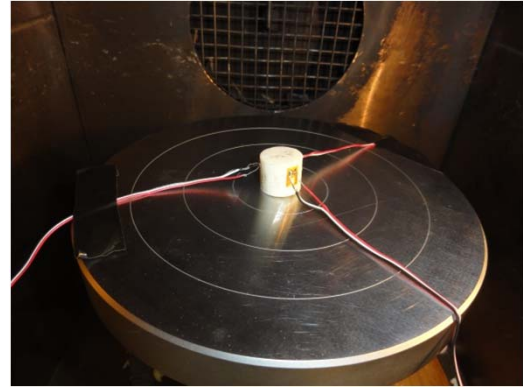
Average Material Properties:

Maximum Load, P_z : 39,252 lbs
 Compressive Strength, SC_z : 69,499 psi
 Compressive Modulus, E_z : 1,280,838 psi
 Ultimate Strain, ϵ_z : 0.055 in/in

Measured Specimen Dimensions:

Thickness, T: 0.730 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,850 psi
 50% Max Load: 19,626 psi

PICTURE OF SPECIMEN PRE-TEST



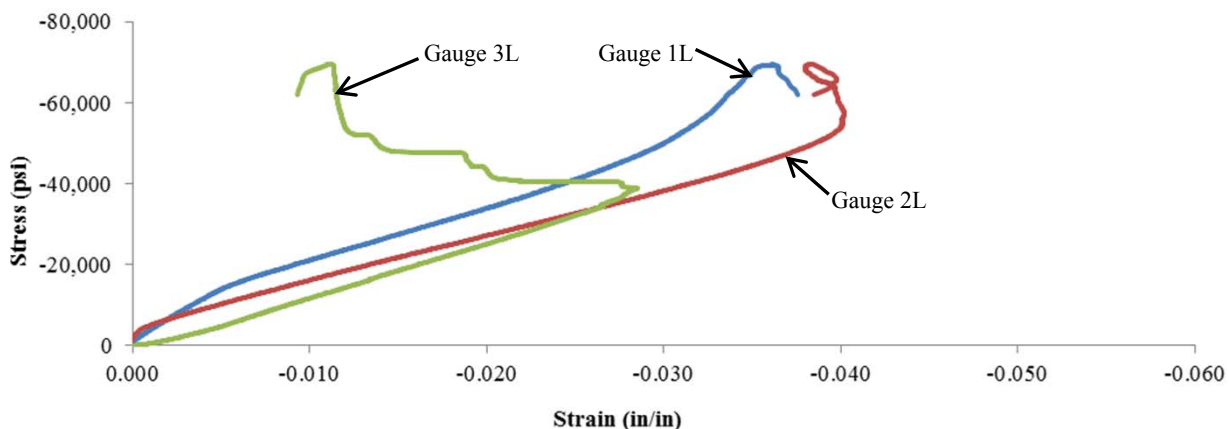
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02067 | 0.00501 | 1,331,940 |
| 2L | 0.02700 | 0.00808 | 1,102,109 |
| 3L | 0.02650 | 0.01170 | 1,408,465 |
| Average | | | 1,280,838 |

Stress-Strain Curve (09-02)_-40°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

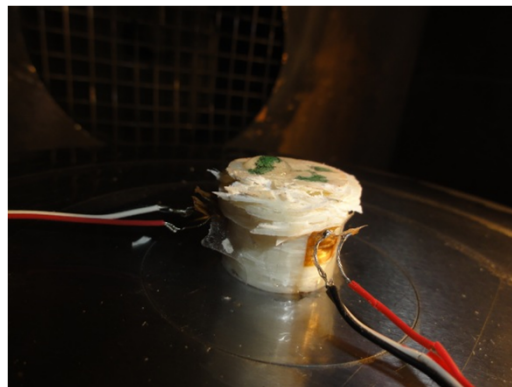
TEST SUMMARY

Specimen ID: **MAT2-CZ-05-N40-FY09**
 Test Date: 6/18/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Maximum Load, P_z : | 41,997 | lbs |
| Compressive Strength, SC_z : | 74,888 | psi |
| Compressive Modulus, E_z : | 1,007,361 | psi |
| Ultimate Strain, ϵ_z : | 0.076 | in/in |

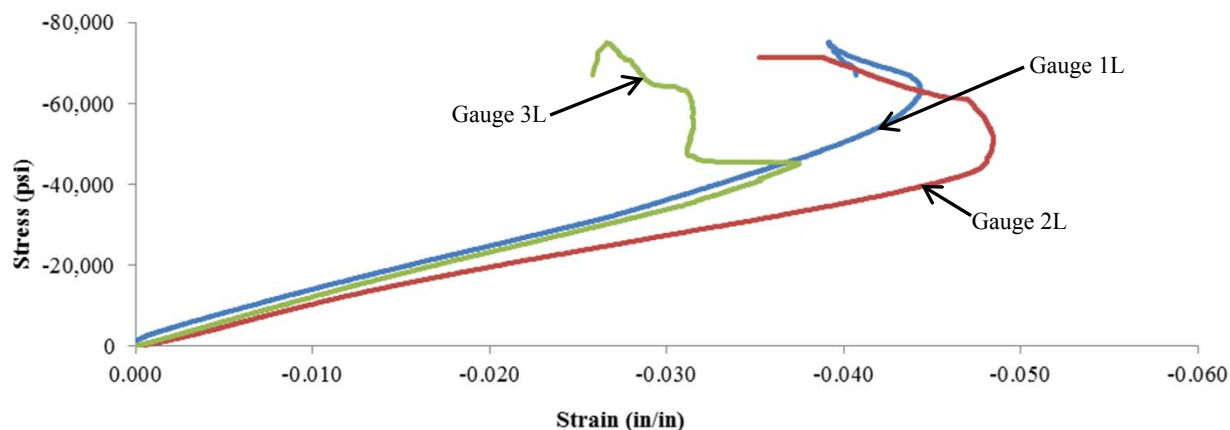
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 0.736 | in |
| Diameter, D: | 0.845 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 20% Max Load: | 8,399 | psi |
| 50% Max Load: | 20,998 | psi |

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03096 | 0.01078 | 1,113,427 |
| 2L | 0.04237 | 0.01466 | 810,594 |
| 3L | 0.03283 | 0.01237 | 1,098,064 |
| Average | | | 1,007,361 |

Stress-Strain Curve (09-02)_-40°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

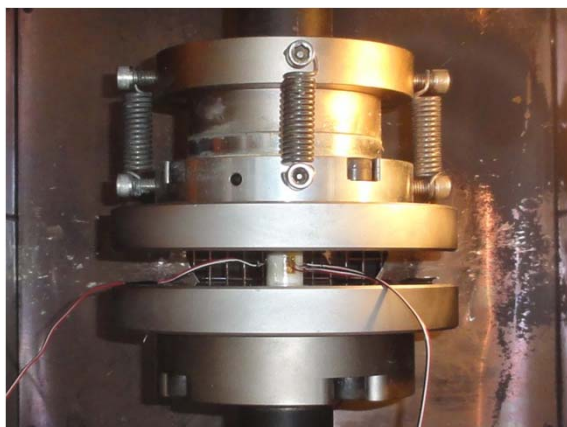
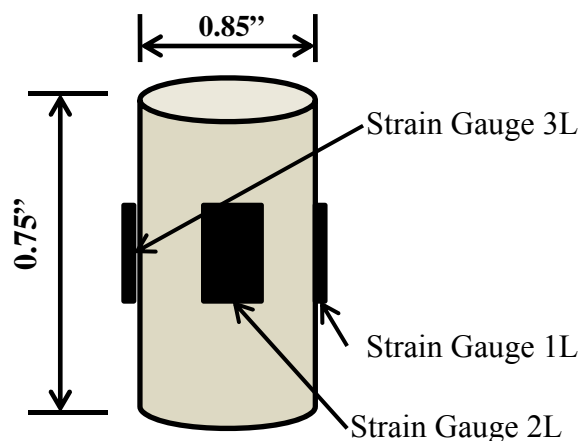
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-CZ-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_z , E_z , ϵ_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **29,161** **lbs**
 Compressive Strength, SC_z : **51,851** **psi**
 Compressive Modulus, E_z : **805,102** **psi**
 Ultimate Strain, ϵ_z : **0.067** **in/in**

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT2-CZ-01-70-FY09 | 29,092 | 51,390 | 889,261 | 0.0600 | Rupture |
| MAT2-CZ-02-70-FY09 | 27,184 | 48,474 | 740,891 | 0.0697 | Rupture |
| MAT2-CZ-03-70-FY09 | 29,703 | 52,468 | 834,247 | 0.0631 | Rupture |
| MAT2-CZ-04-70-FY09 | 30,528 | 54,309 | 685,168 | 0.0796 | Rupture |
| MAT2-CZ-05-70-FY09 | 29,296 | 52,613 | 875,943 | 0.0608 | Rupture |
| Average | 29,161 | 51,851 | 805,102 | 0.067 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-80 to E-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-70-FY09**
 Test Date: 5/18/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 29,092 lbs
 Compressive Strength, SC_z : 51,390 psi
 Compressive Modulus, E_z : 889,261 psi
 Ultimate Strain, ϵ_z : 0.060 in/in

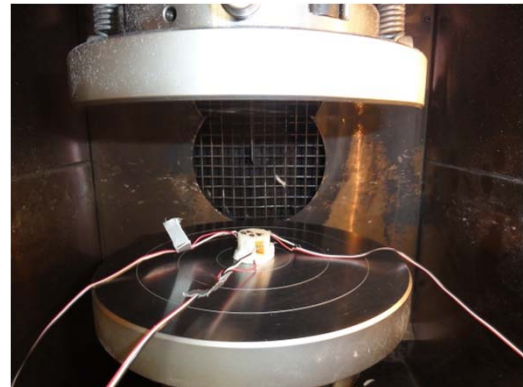
Measured Specimen Dimensions:

Thickness, T: 0.725 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,818 psi
 50% Max Load: 14,546 psi

PICTURE OF SPECIMEN PRE-TEST



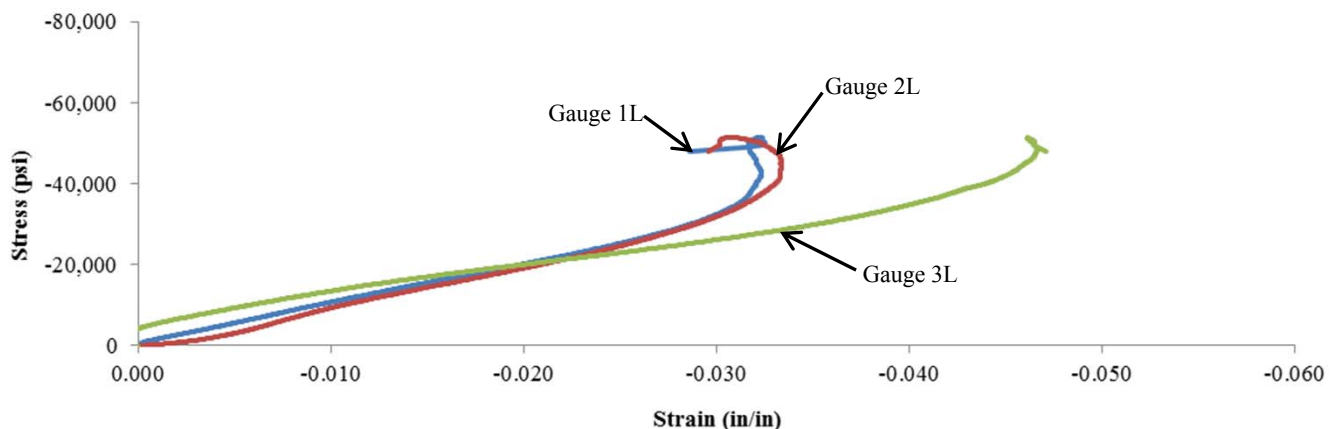
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02538 | 0.00954 | 973,538 |
| 2L | 0.02586 | 0.01089 | 1,029,650 |
| 3L | 0.02931 | 0.00611 | 664,597 |
| Average | | | 889,261 |

Stress-Strain Curve (09-02)_70°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-70-FY09**
 Test Date: 5/21/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

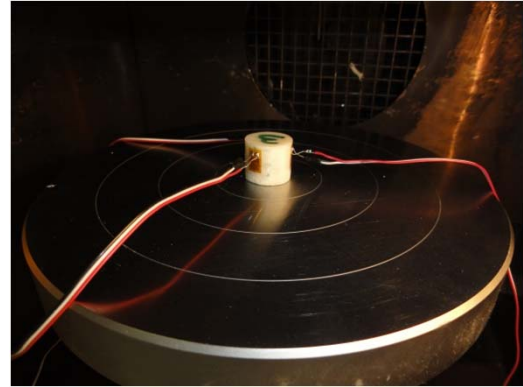
Average Material Properties:

| | | |
|---------------------------------|---------|-------|
| Maximum Load, P_z : | 27,184 | lbs |
| Compressive Strength, SC_z : | 48,474 | psi |
| Compressive Modulus, E_z : | 740,891 | psi |
| Ultimate Strain, ϵ_z : | 0.070 | in/in |

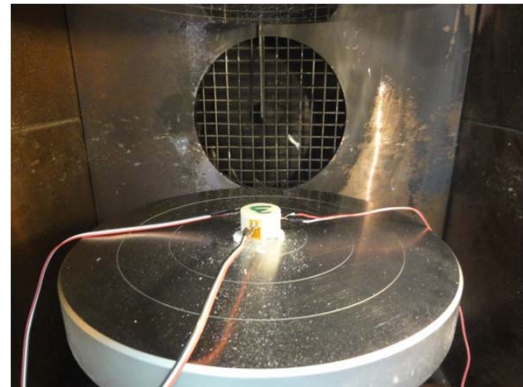
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 0.718 | in |
| Diameter, D: | 0.845 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 20% Max Load: | 5,437 | psi |
| 50% Max Load: | 13,592 | psi |

PICTURE OF SPECIMEN PRE-TEST



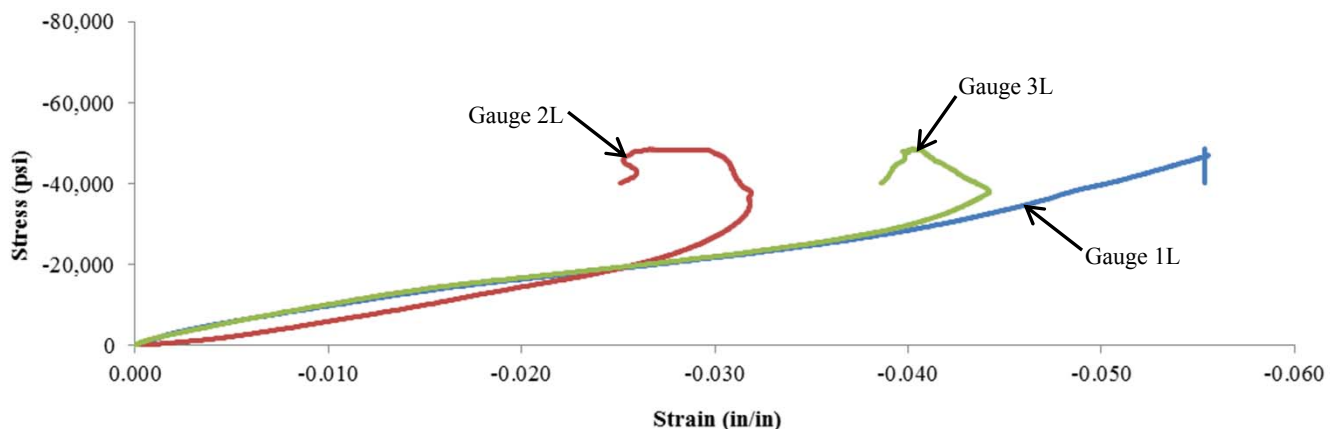
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03421 | 0.00981 | 596,037 |
| 2L | 0.02876 | 0.01457 | 1,025,048 |
| 3L | 0.03355 | 0.00938 | 601,588 |
| Average | | | 740,891 |

Stress-Strain Curve (09-02)_70°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-70-FY09**
 Test Date: 5/21/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

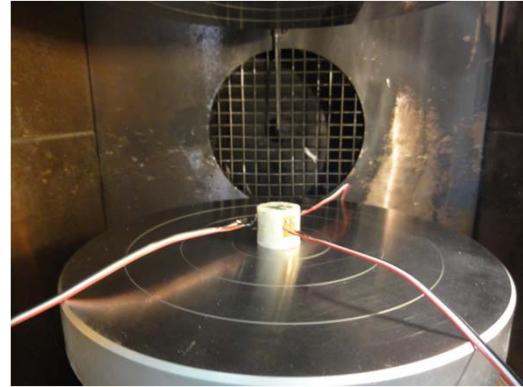
Average Material Properties:

Maximum Load, P_z : 29,703 lbs
 Compressive Strength, SC_z : 52,468 psi
 Compressive Modulus, E_z : 834,247 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

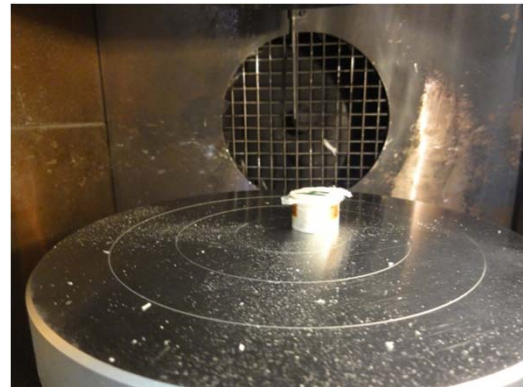
Measured Specimen Dimensions:

Thickness, T: 0.723 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,941 psi
 50% Max Load: 14,851 psi

PICTURE OF SPECIMEN PRE-TEST



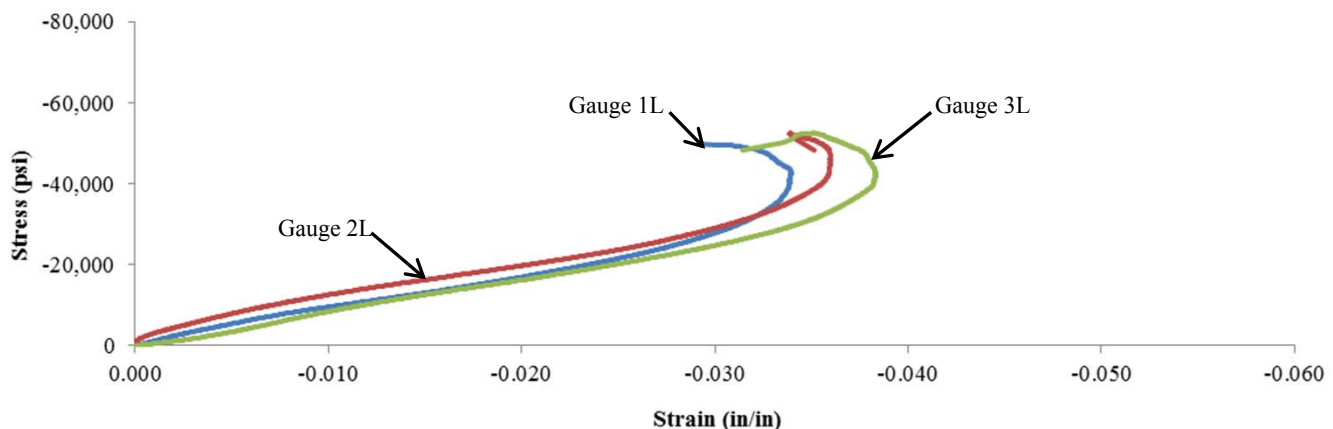
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02895 | 0.01129 | 891,474 |
| 2L | 0.02762 | 0.00757 | 785,165 |
| 3L | 0.03139 | 0.01234 | 826,102 |
| Average | | | 834,247 |

Stress-Strain Curve (09-02)_70°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-70-FY09**
 Test Date: 5/21/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

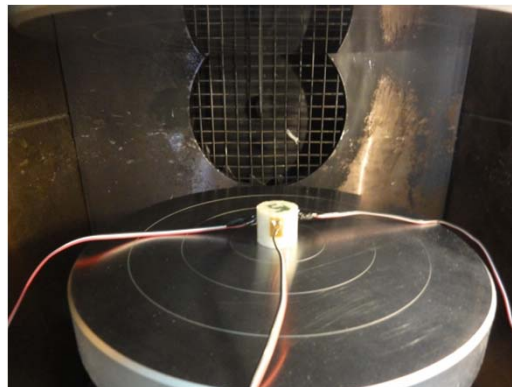
Average Material Properties:

Maximum Load, P_z : 30,528 lbs
 Compressive Strength, SC_z : 54,309 psi
 Compressive Modulus, E_z : 685,168 psi
 Ultimate Strain, ϵ_z : 0.080 in/in

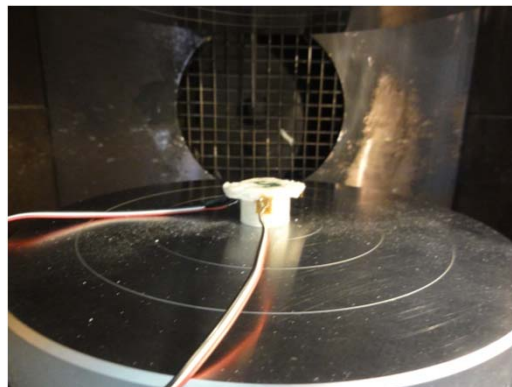
Measured Specimen Dimensions:

Thickness, T: 0.724 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,106 psi
 50% Max Load: 15,264 psi

PICTURE OF SPECIMEN PRE-TEST



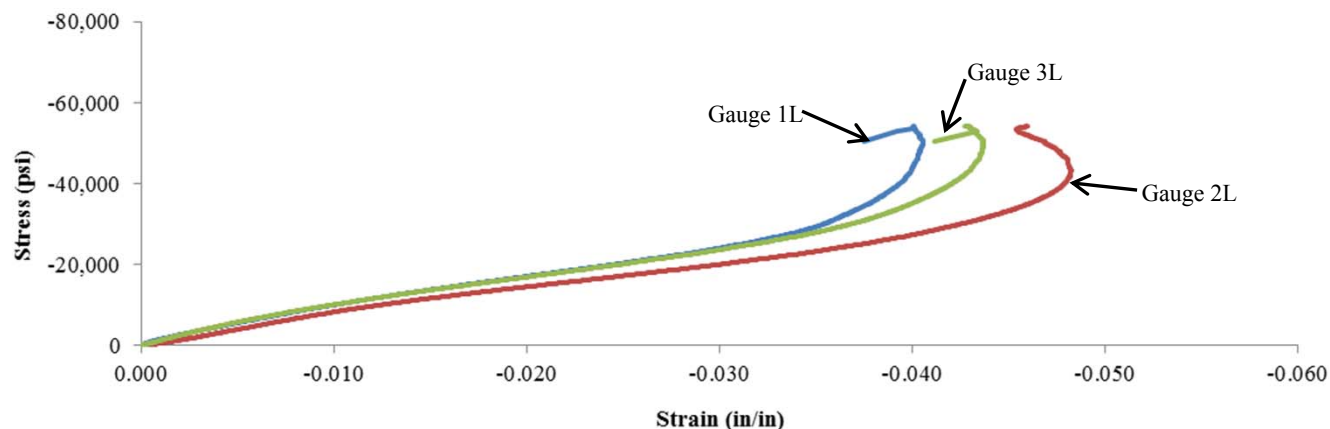
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03332 | 0.01103 | 731,242 |
| 2L | 0.03983 | 0.01368 | 622,939 |
| 3L | 0.03423 | 0.01100 | 701,322 |
| Average | | | 685,168 |

Stress-Strain Curve (09-02)_70°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-05-70-FY09**
 Test Date: 5/21/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

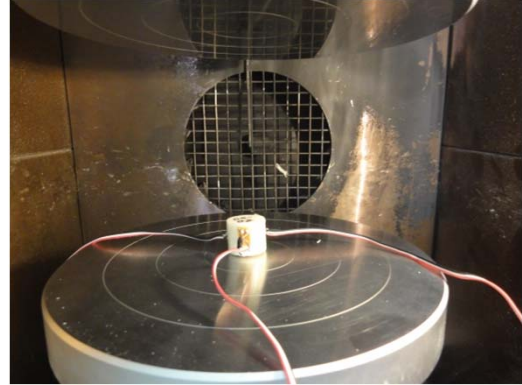
Average Material Properties:

Maximum Load, P_z : 29,296 lbs
 Compressive Strength, SC_z : 52,613 psi
 Compressive Modulus, E_z : 875,943 psi
 Ultimate Strain, ϵ_z : 0.061 in/in

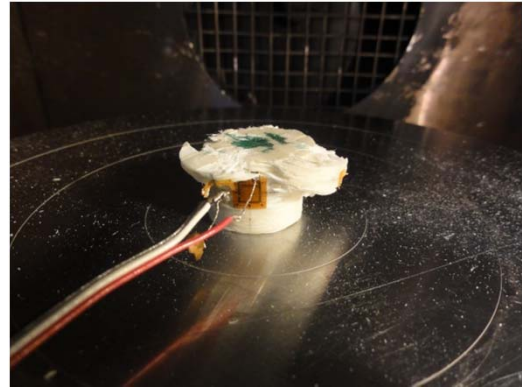
Measured Specimen Dimensions:

Thickness, T: 0.726 in
 Diameter, D: 0.842 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,859 psi
 50% Max Load: 14,648 psi

PICTURE OF SPECIMEN PRE-TEST



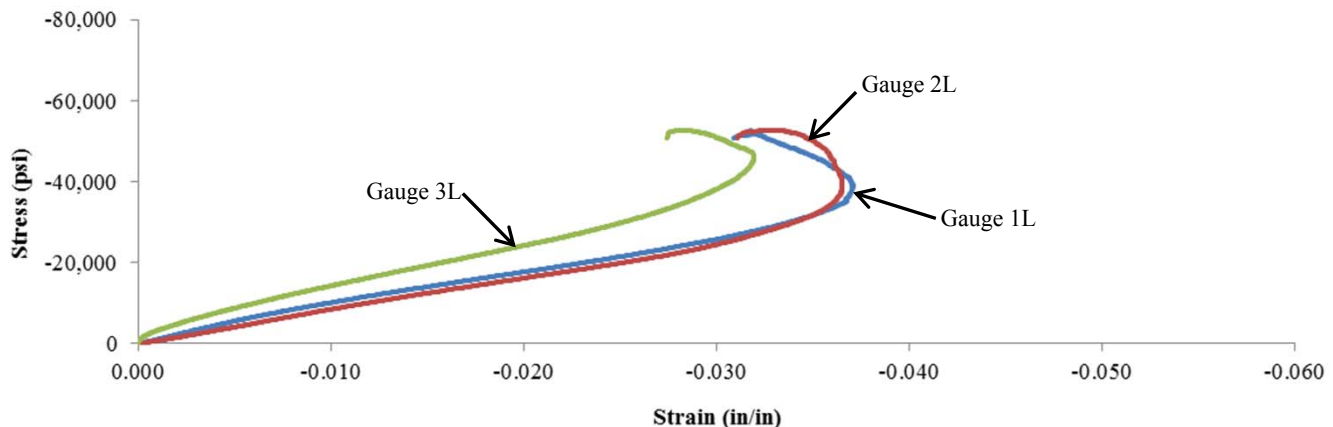
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03054 | 0.01045 | 785,375 |
| 2L | 0.03151 | 0.01246 | 828,696 |
| 3L | 0.02206 | 0.00649 | 1,013,759 |
| Average | | | 875,943 |

Stress-Strain Curve (09-02)_70°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

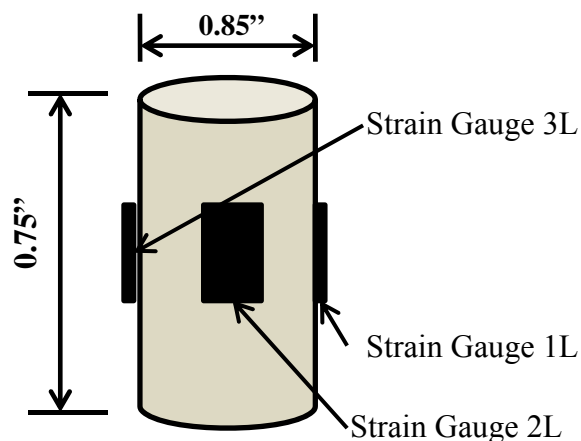
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-CZ-140-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 27,352 lbs
 Compressive Strength, SC_z : 48,680 psi
 Compressive Modulus, E_z : 896,758 psi
 Ultimate Strain, ϵ_z : 0.057 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT2-CZ-01-140-FY09 | 27,486 | 49,013 | 860,122 | 0.0579 | Rupture |
| MAT2-CZ-02-140-FY09 | 26,887 | 47,944 | 748,837 | 0.0663 | Rupture |
| MAT2-CZ-03-140-FY09 | 28,119 | 49,670 | 1,014,089 | 0.0516 | Rupture |
| MAT2-CZ-04-140-FY09 | 27,173 | 48,340 | 907,720 | 0.0587 | Rupture |
| MAT2-CZ-05-140-FY09 | 27,096 | 48,431 | 953,024 | 0.0524 | Rupture |
| Average | 27,352 | 48,680 | 896,758 | 0.057 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test ConditionNominal Dimensions/
Strain Gauge ConfigurationNotes:

- 1) Reference E-86 to E-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-01-140-FY09**
 Test Date: 5/22/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 27,486 lbs
 Compressive Strength, SC_z : 49,013 psi
 Compressive Modulus, E_z : 860,122 psi
 Ultimate Strain, ϵ_z : 0.058 in/in

Measured Specimen Dimensions:

Thickness, T: 0.729 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,749 psi
 40% Max Load: 10,994 psi

PICTURE OF SPECIMEN PRE-TEST



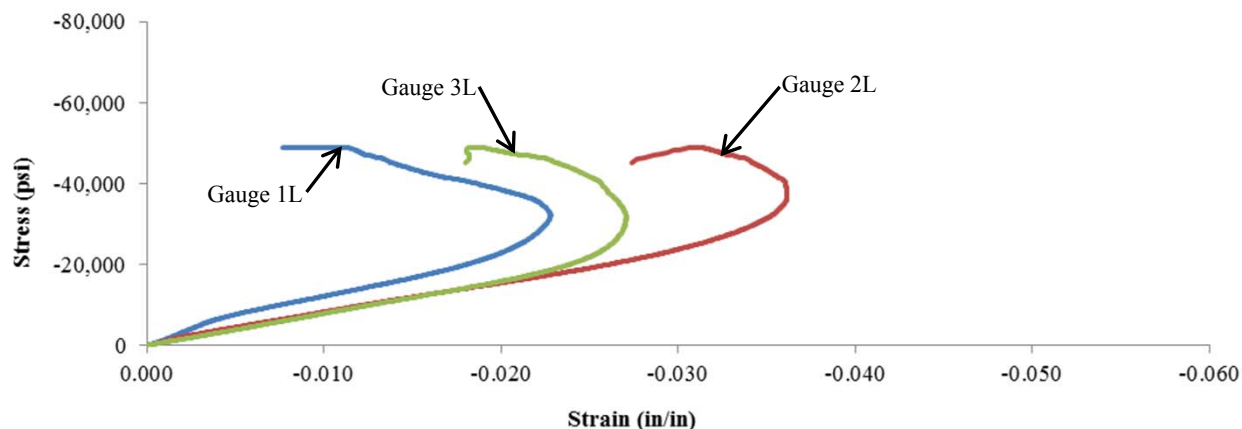
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.01768 | 0.00294 | 997,268 |
| 2L | 0.02554 | 0.00546 | 732,419 |
| 3L | 0.02353 | 0.00624 | 850,678 |
| Average | | | 860,122 |

Stress-Strain Curve (09-02)_140°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-02-140-FY09**
 Test Date: 5/22/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

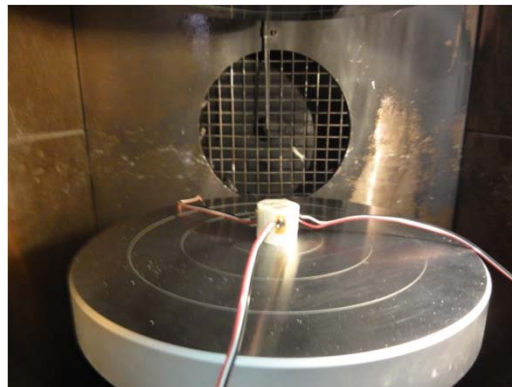
Average Material Properties:

Maximum Load, P_z : 26,887 lbs
 Compressive Strength, SC_z : 47,944 psi
 Compressive Modulus, E_z : 748,837 psi
 Ultimate Strain, ϵ_z : 0.066 in/in

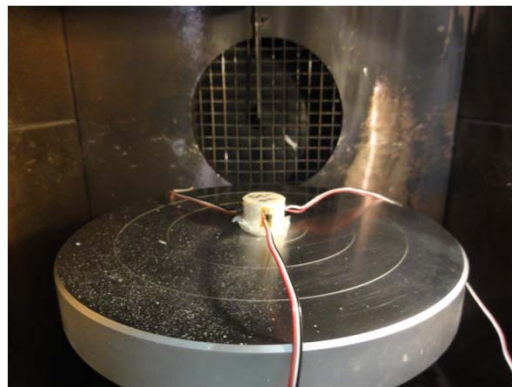
Measured Specimen Dimensions:

Thickness, T: 0.735 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,689 psi
 40% Max Load: 10,755 psi

PICTURE OF SPECIMEN PRE-TEST



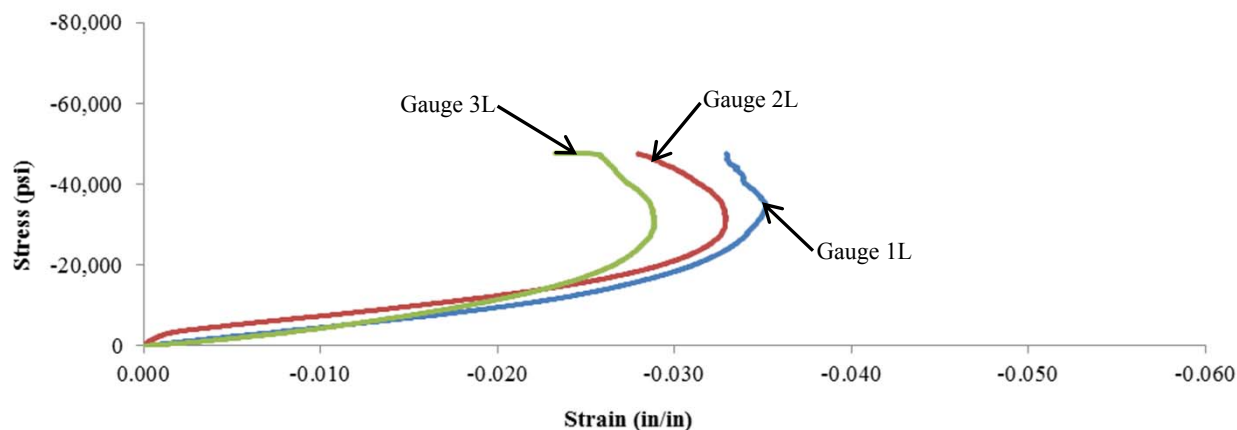
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03052 | 0.01054 | 719,645 |
| 2L | 0.02855 | 0.00429 | 592,780 |
| 3L | 0.02614 | 0.01075 | 934,085 |
| Average | | | 748,837 |

Stress-Strain Curve (09-02)_140°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-03-140-FY09**
 Test Date: 5/22/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

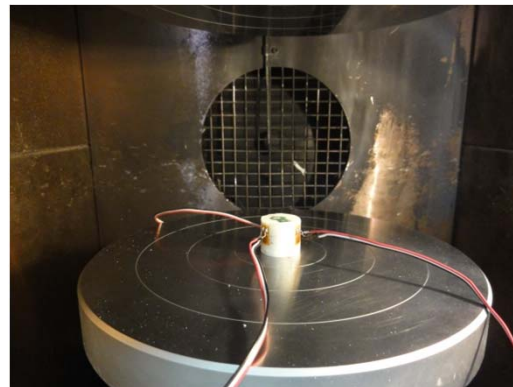
Average Material Properties:

Maximum Load, P_z : 28,119 lbs
 Compressive Strength, SC_z : 49,670 psi
 Compressive Modulus, E_z : 1,014,089 psi
 Ultimate Strain, ϵ_z : 0.052 in/in

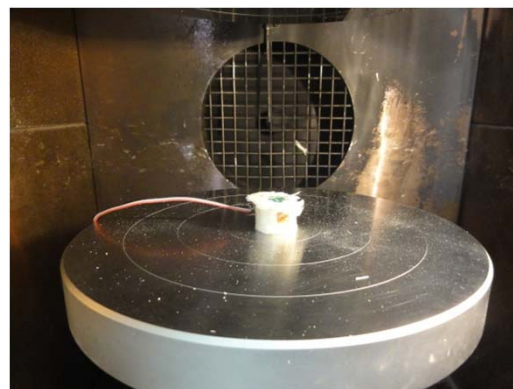
Measured Specimen Dimensions:

Thickness, T: 0.720 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,812 psi
 40% Max Load: 11,248 psi

PICTURE OF SPECIMEN PRE-TEST



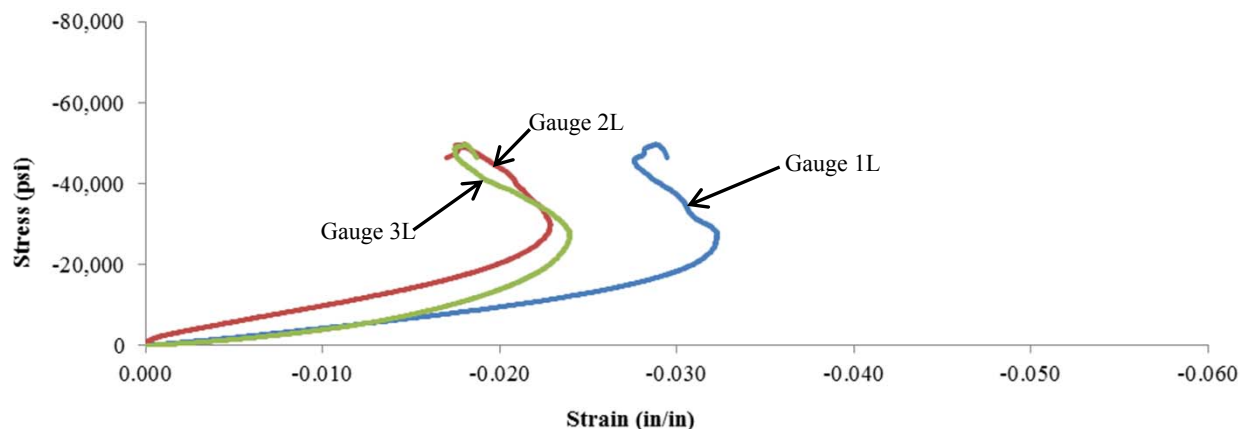
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 10% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03083 | 0.01137 | 765,532 |
| 2L | 0.01975 | 0.00386 | 938,100 |
| 3L | 0.02278 | 0.01165 | 1,338,637 |
| Average | | | 1,014,089 |

Stress-Strain Curve (09-02)_140°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-04-140-FY09**
 Test Date: 5/22/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

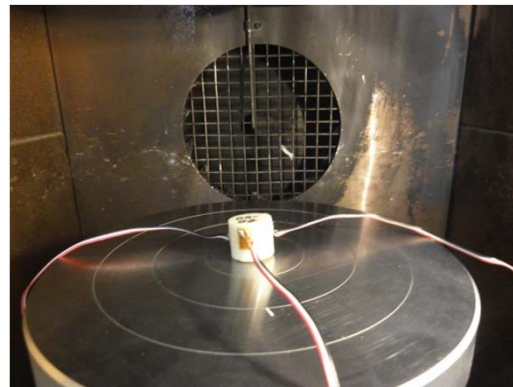
Average Material Properties:

| | | |
|---------------------------------|---------|-------|
| Maximum Load, P_z : | 27,173 | lbs |
| Compressive Strength, SC_z : | 48,340 | psi |
| Compressive Modulus, E_z : | 907,720 | psi |
| Ultimate Strain, ϵ_z : | 0.059 | in/in |

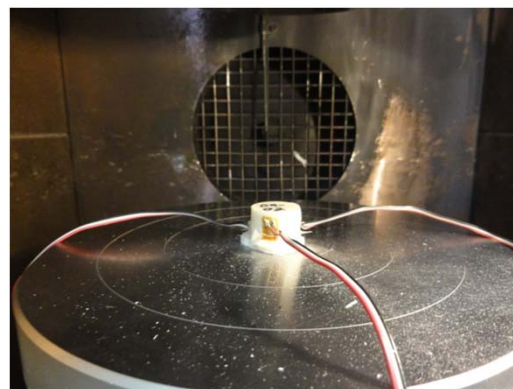
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 0.724 | in |
| Diameter, D: | 0.846 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 10% Max Load: | 2,717 | psi |
| 40% Max Load: | 10,869 | psi |

PICTURE OF SPECIMEN PRE-TEST



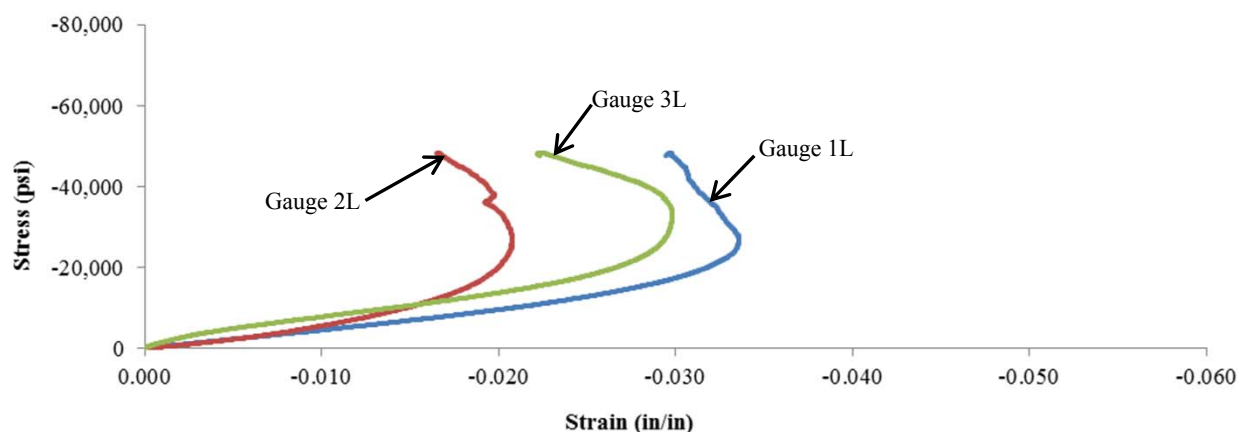
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 10% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03135 | 0.01059 | 698,603 |
| 2L | 0.01980 | 0.00901 | 1,343,769 |
| 3L | 0.02610 | 0.00480 | 680,789 |
| Average | | | 907,720 |

Stress-Strain Curve (09-02)_140°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-CZ-05-140-FY09**
 Test Date: 5/24/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

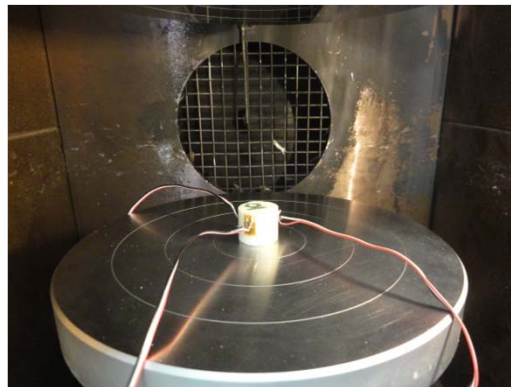
Average Material Properties:

Maximum Load, P_z : 27,096 lbs
 Compressive Strength, SC_z : 48,431 psi
 Compressive Modulus, E_z : 953,024 psi
 Ultimate Strain, ϵ_z : 0.052 in/in

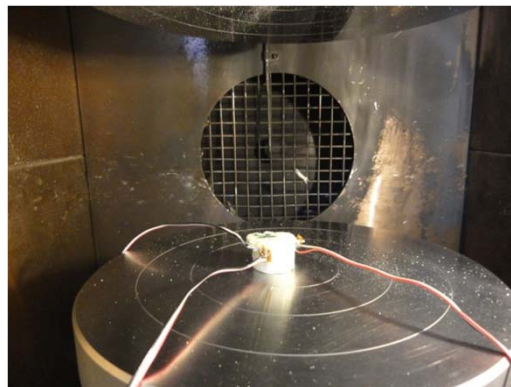
Measured Specimen Dimensions:

Thickness, T: 0.731 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 10% Max Load: 2,710 psi
 40% Max Load: 10,838 psi

PICTURE OF SPECIMEN PRE-TEST



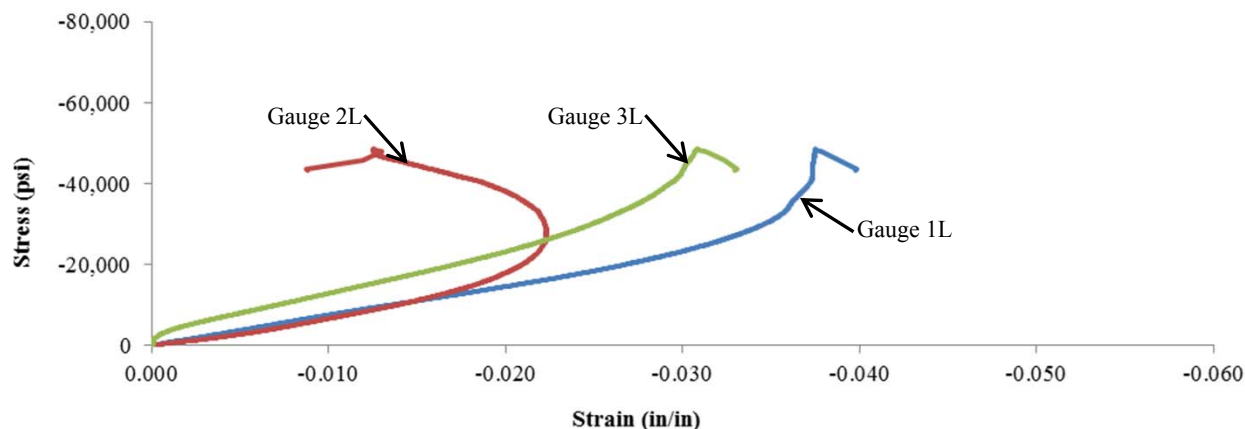
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 10% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02605 | 0.00643 | 740,396 |
| 2L | 0.02066 | 0.00779 | 1,129,412 |
| 3L | 0.01653 | 0.00185 | 989,266 |
| Average | | | 953,024 |

Stress-Strain Curve (09-02)_140°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-SXZ-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 606 lbs

Shear Strength, S_{xz} : 4,780 psi

Shear Modulus, G_{xz} : 603,574 psi

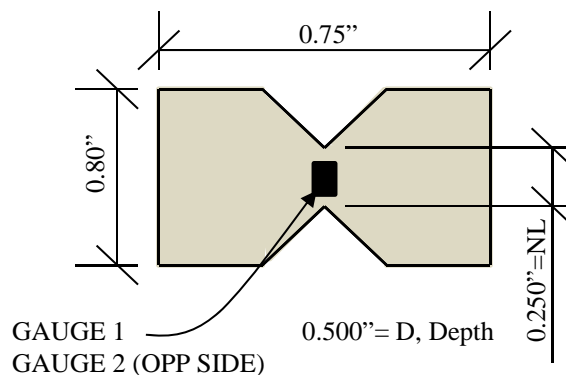
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|-------------------------------|--------------------------------|-------------------------------|--------------|
| MAT2-SXZ-01-N40-FY09 | 601 | 4,881 | 593,331 | Shear |
| MAT2-SXZ-02-N40-FY09 | 585 | 4,661 | 595,799 | Shear |
| MAT2-SXZ-03-N40-FY09 | 641 | 4,855 | 548,227 | Shear |
| MAT2-SXZ-04-N40-FY09 | 643 | 4,946 | 634,296 | Shear |
| MAT2-SXZ-05-N40-FY09 | 559 | 4,555 | 646,216 | Shear |
| Average | 606 | 4,780 | 603,574 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets E-92 to E-96
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-01-N40-FY09**
 Test Date: 7/06/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

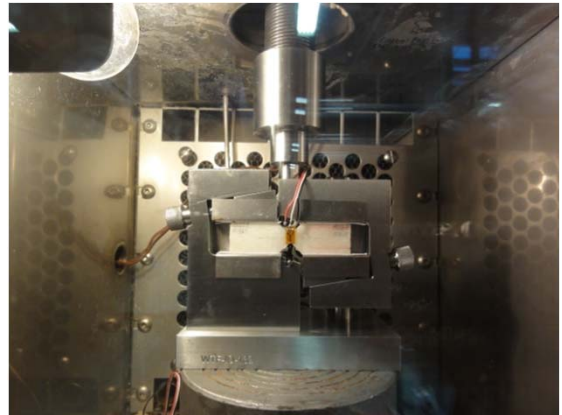
Average Material Properties:

Ultimate Load, P_{max} : **601** **lbs**
Shear Strength, S_{xz} : **4,881** **psi**
Shear Modulus, G_{xz} : **593,331** **psi**

Measured Specimen Dimensions:

Depth, D: 0.468 in
 Notch Length, NL: 0.263 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 300 lbs
 20% Max Load: 120 lbs

PICTURE OF SPECIMEN PRE-TEST



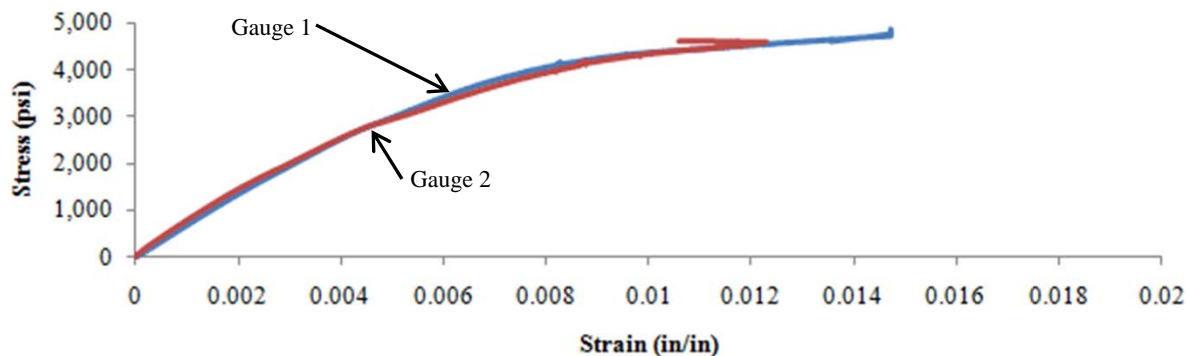
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0038 | 0.0014 | 608,589 |
| 2 | 0.0038 | 0.0013 | 578,073 |
| Average | | | 593,331 |

Stress-Strain Curve -40°F_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-02-N40-FY09**
 Test Date: 7/06/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

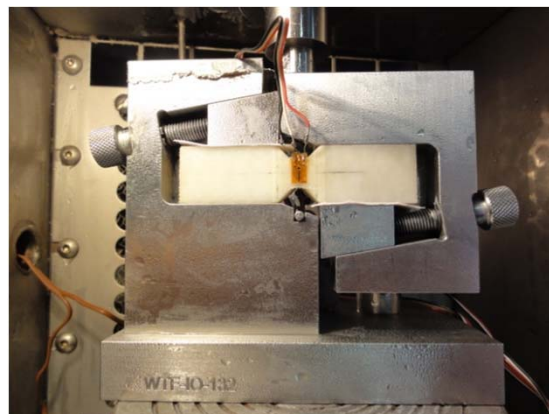
Average Material Properties:

Ultimate Load, P_{max} : **585** lbs
 Shear Strength, S_{xz} : **4,661** psi
 Shear Modulus, G_{xz} : **595,799** psi

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, NL: 0.254 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 292 lbs
 20% Max Load: 117 lbs

PICTURE OF SPECIMEN PRE-TEST



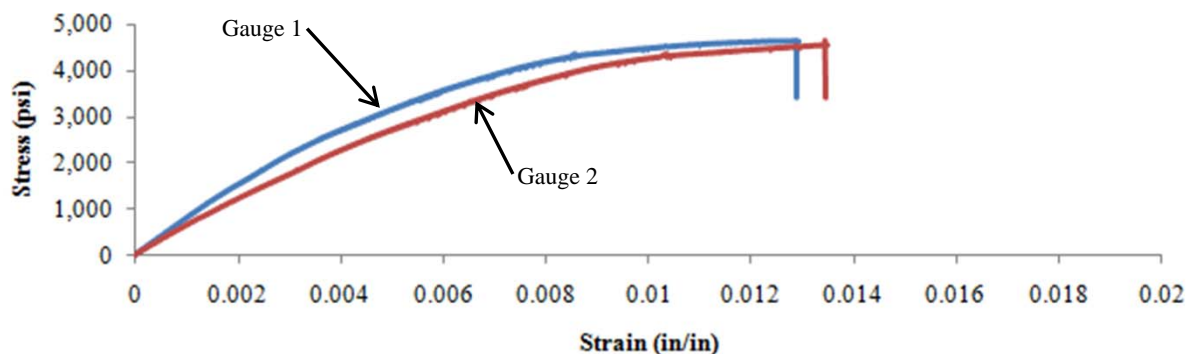
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0032 | 0.0011 | 662,949 |
| 2 | 0.0041 | 0.0015 | 528,649 |
| Average | | | 595,799 |

Stress-Strain Curve -40°F_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-03-N40-FY09**
 Test Date: 7/07/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

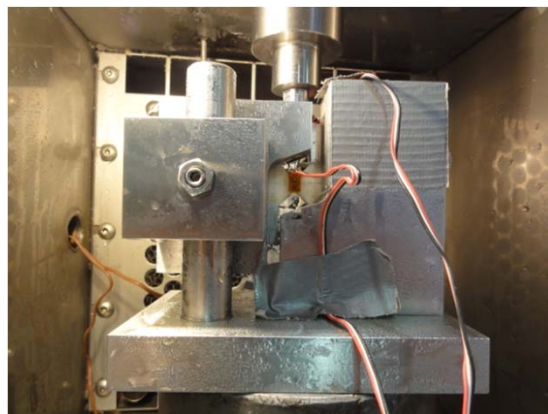
Average Material Properties:

Ultimate Load, P_{max} : **641** lbs
 Shear Strength, S_{xz} : **4,855** psi
 Shear Modulus, G_{xz} : **548,227** psi

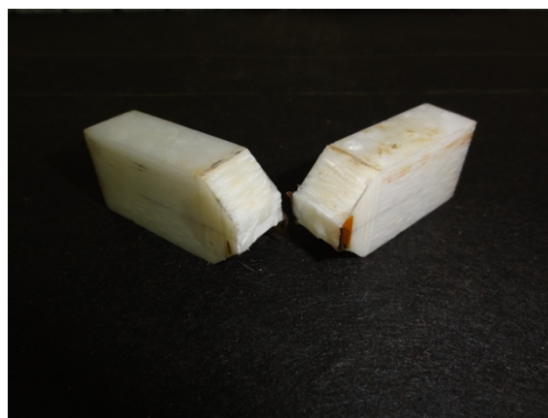
Measured Specimen Dimensions:

Depth, D: 0.508 in
 Notch Length, NL: 0.260 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 321 lbs
 20% Max Load: 128 lbs

PICTURE OF SPECIMEN PRE-TEST



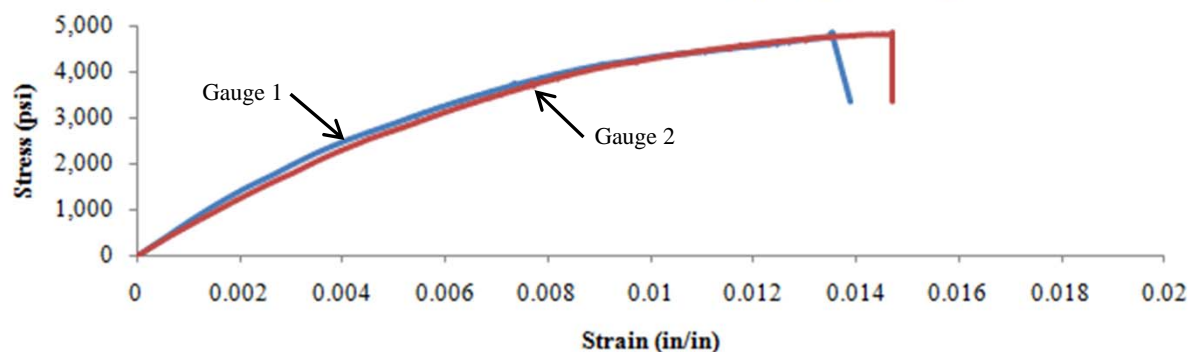
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0039 | 0.0013 | 565,482 |
| 2 | 0.0043 | 0.0015 | 530,972 |
| Average | | | 548,227 |

Stress-Strain Curve -40°F_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-04-N40-FY09**
 Test Date: 7/08/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

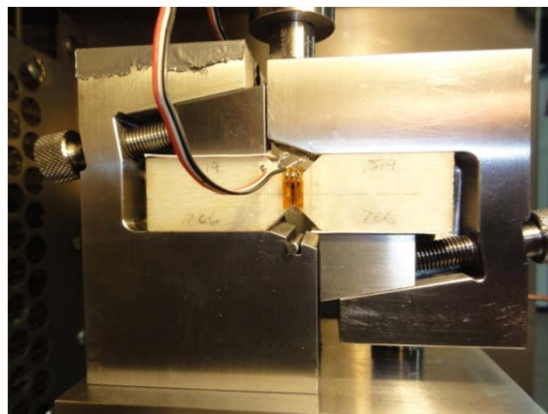
Average Material Properties:

Ultimate Load, P_{max} : **643** lbs
 Shear Strength, S_{xz} : **4,946** psi
 Shear Modulus, G_{xz} : **634,296** psi

Measured Specimen Dimensions:

Depth, D: 0.504 in
 Notch Length, NL: 0.258 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 322 lbs
 20% Max Load: 129 lbs

PICTURE OF SPECIMEN PRE-TEST



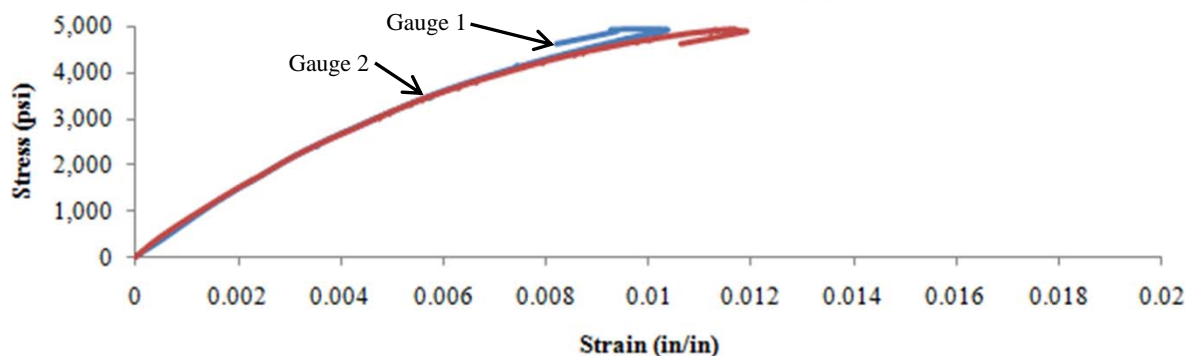
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0036 | 0.0013 | 642,995 |
| 2 | 0.0036 | 0.0012 | 625,597 |
| Average | | | 634,296 |

Stress-Strain Curve -40°F_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-05-N40-FY09**
 Test Date: 8/08/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

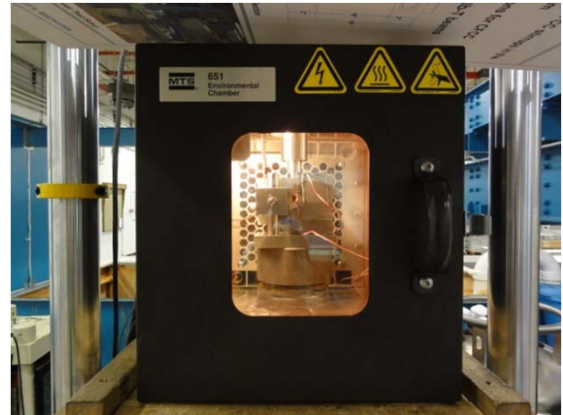
Average Material Properties:

Ultimate Load, P_{max} : **559** lbs
 Shear Strength, S_{xz} : **4,555** psi
 Shear Modulus, G_{xz} : **646,216** psi

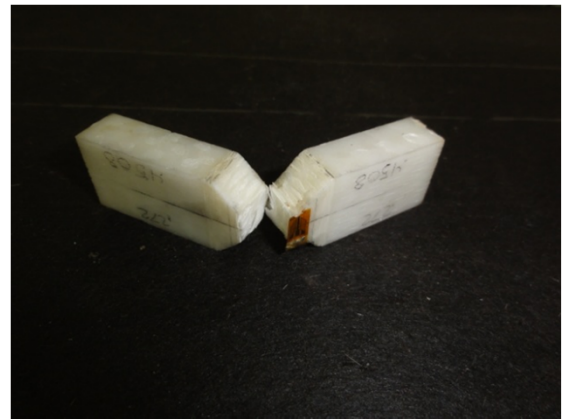
Measured Specimen Dimensions:

Depth, D: 0.451 in
 Notch Length, NL: 0.272 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 279 lbs
 20% Max Load: 112 lbs

PICTURE OF SPECIMEN PRE-TEST



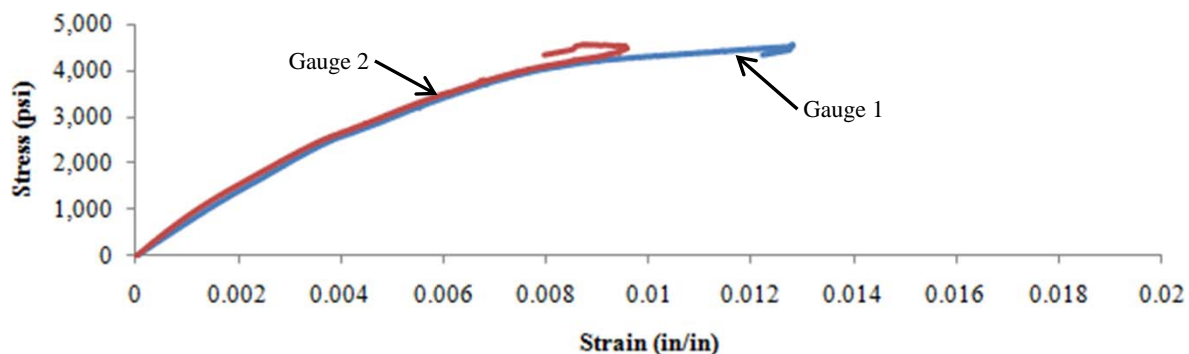
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0038 | 0.0017 | 650,056 |
| 2 | 0.0036 | 0.0015 | 642,376 |
| Average | | | 646,216 |

Stress-Strain Curve -40°F_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-SXZ-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 362 lbs

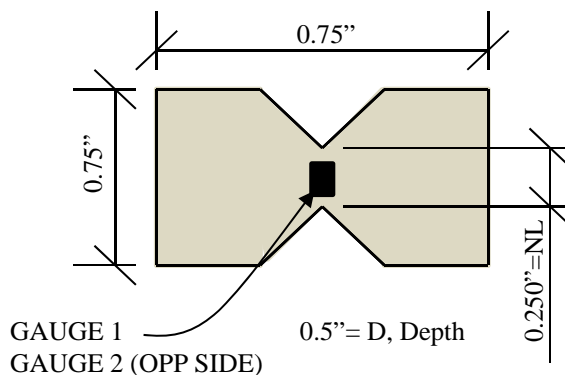
Shear Strength, S_{xz} : 2,923 psi

Shear Modulus, G_{xz} : 457,242 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT2-SXZ-01-70-FY09 | 385 | 3,110 | 453,095 | Shear |
| MAT2-SXZ-02-70-FY09 | 362 | 3,033 | 464,989 | Shear |
| MAT2-SXZ-03-70-FY09 | 332 | 2,642 | 446,975 | Shear |
| MAT2-SXZ-04-70-FY09 | 338 | 2,702 | 456,361 | Shear |
| MAT2-SXZ-05-70-FY09 | 392 | 3,126 | 464,789 | Shear |
| Average | 362 | 2,923 | 457,242 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets E-98 to E-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-01-70-FY09**
 Test Date: 6/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

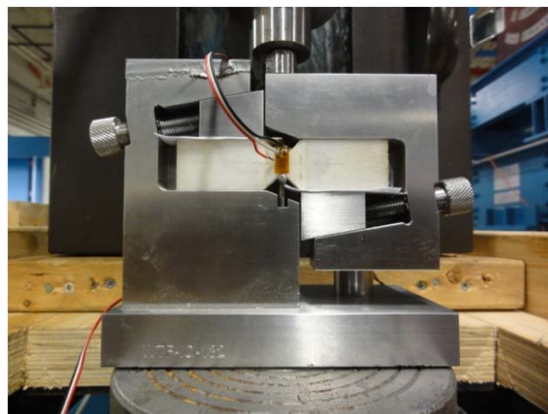
Average Material Properties:

Ultimate Load, P_{max} : **385** lbs
 Shear Strength, S_{xz} : **3,110** psi
 Shear Modulus, G_{xz} : **453,095** psi

Measured Specimen Dimensions:

Depth, D: 0.489 in
 Notch Length, NL: 0.253 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 192 lbs
 20% Max Load: 77 lbs

PICTURE OF SPECIMEN PRE-TEST



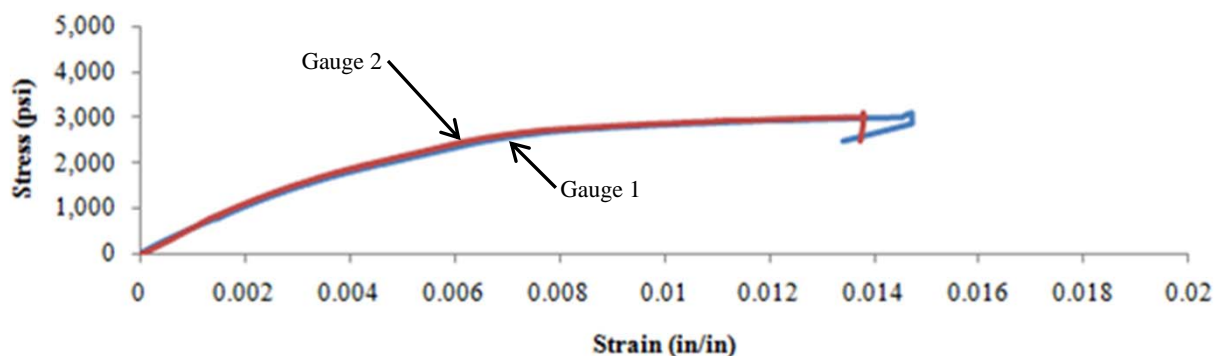
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0032 | 0.0011 | 434,805 |
| 2 | 0.0030 | 0.0011 | 471,384 |
| Average | | | 453,095 |

Stress-Strain Curve 70_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-02-70-FY09**
 Test Date: 6/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

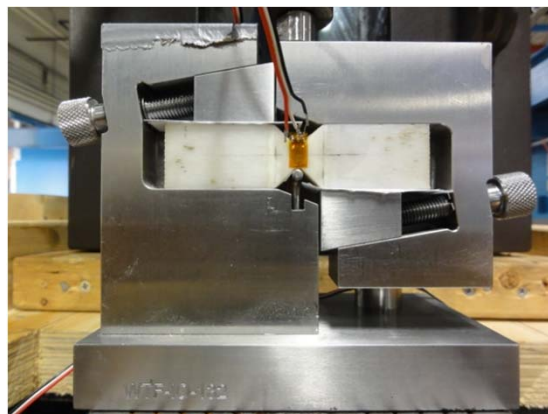
Average Material Properties:

Ultimate Load, P_{max} : **362** **lbs**
Shear Strength, S_{xz} : **3,033** **psi**
Shear Modulus, G_{xz} : **464,989** **psi**

Measured Specimen Dimensions:

Depth, D: 0.470 in
 Notch Length, NL: 0.254 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 181 lbs
 20% Max Load: 72 lbs

PICTURE OF SPECIMEN PRE-TEST



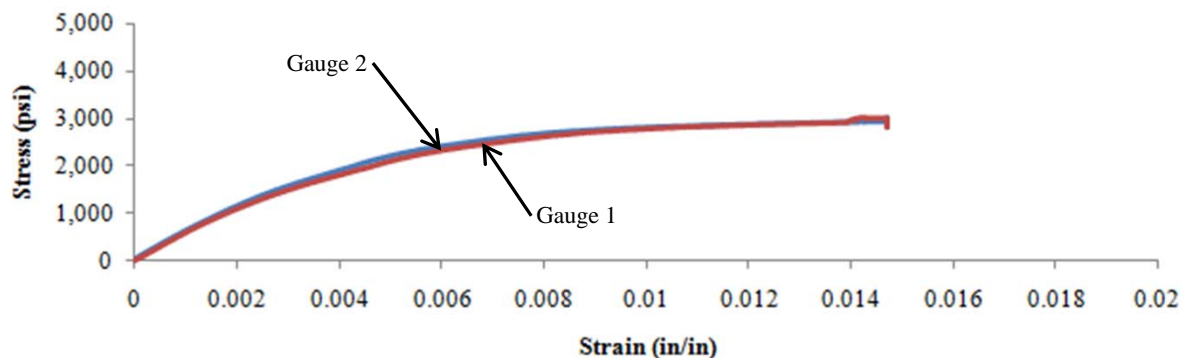
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0028 | 0.0010 | 483,039 |
| 2 | 0.0031 | 0.0010 | 446,939 |
| Average | | | 464,989 |

Stress-Strain Curve 70_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-03-70-FY09**
 Test Date: 6/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

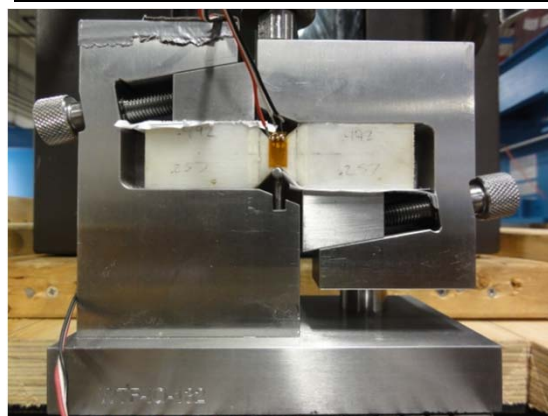
Average Material Properties:

Ultimate Load, P_{max} : 332 lbs
Shear Strength, S_{xz} : 2,642 psi
Shear Modulus, G_{xz} : 446,975 psi

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, NL: 0.254 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 166 lbs
 20% Max Load: 66 lbs

PICTURE OF SPECIMEN PRE-TEST



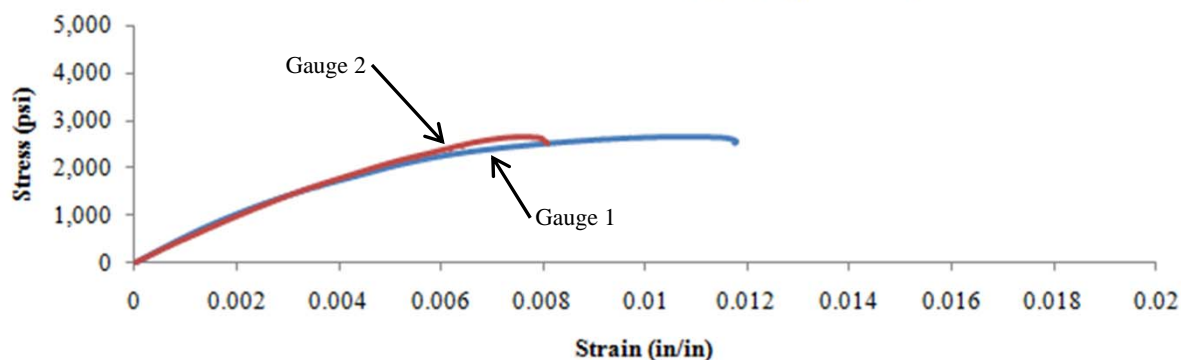
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0027 | 0.0009 | 441,206 |
| 2 | 0.0028 | 0.0010 | 452,743 |
| Average | | | 446,975 |

Stress-Strain Curve 70_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-04-70-FY09**
 Test Date: 6/28/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

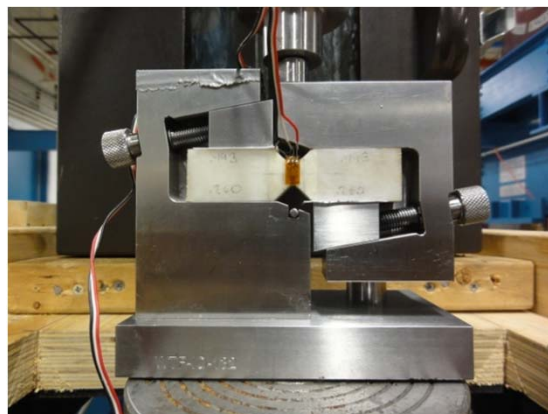
Average Material Properties:

Ultimate Load, P_{max} : **338** lbs
 Shear Strength, S_{xz} : **2,702** psi
 Shear Modulus, G_{xz} : **456,361** psi

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.253 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 169 lbs
 20% Max Load: 68 lbs

PICTURE OF SPECIMEN PRE-TEST



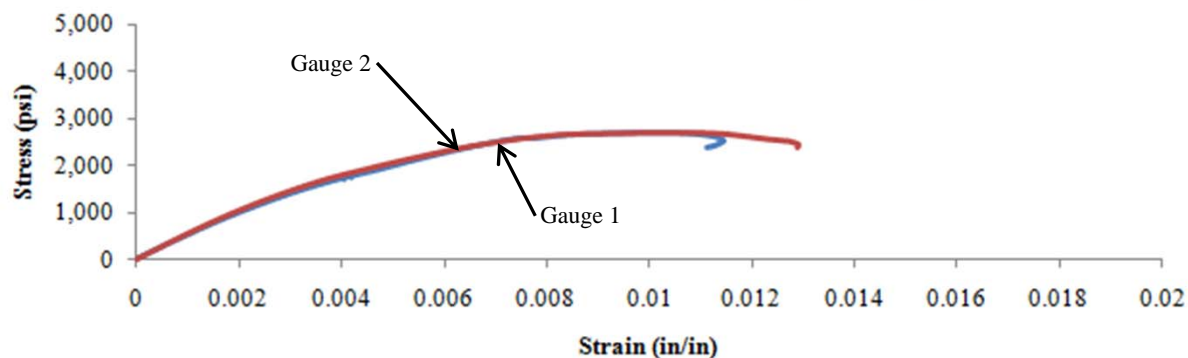
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0028 | 0.0010 | 444,030 |
| 2 | 0.0027 | 0.0010 | 468,692 |
| Average | | | 456,361 |

Stress-Strain Curve 70_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-05-70-FY09**
 Test Date: 6/29/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

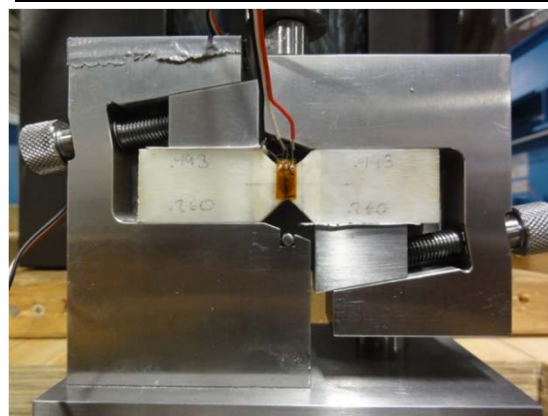
Average Material Properties:

Ultimate Load, P_{max} : **392** lbs
 Shear Strength, S_{xz} : **3,126** psi
 Shear Modulus, G_{xz} : **464,789** psi

Measured Specimen Dimensions:

Depth, D: 0.492 in
 Notch Length, NL: 0.255 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 196 lbs
 20% Max Load: 78 lbs

PICTURE OF SPECIMEN PRE-TEST



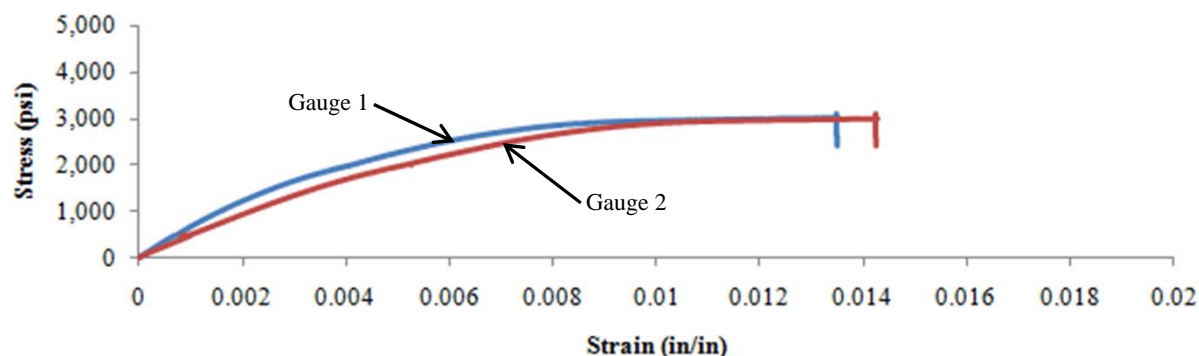
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0027 | 0.0009 | 519,230 |
| 2 | 0.0036 | 0.0013 | 410,348 |
| Average | | | 464,789 |

Stress-Strain Curve 70_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

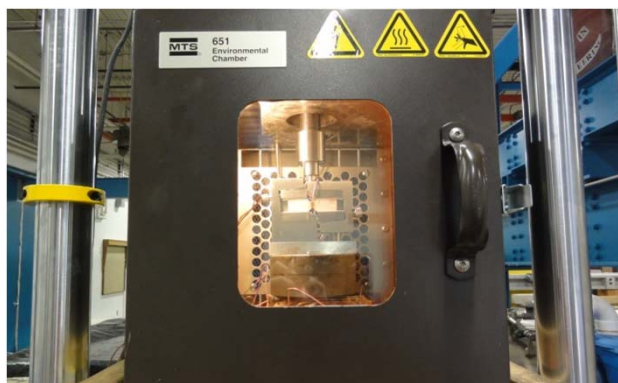
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT2-SXZ-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **135** **lbs**
 Shear Strength, S_{xz} : **1,019** **psi**
 Shear Modulus, G_{xz} : **43,716** **psi**

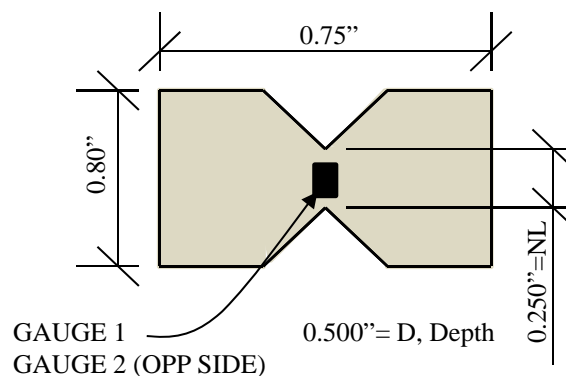
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT2-SXZ-01-140-FY09 | 136 | 1,017 | 43,142 | Shear |
| MAT2-SXZ-02-140-FY09 | 137 | 1,009 | 40,006 | Shear |
| MAT2-SXZ-03-140-FY09 | 129 | 1,055 | 53,042 | Shear |
| MAT2-SXZ-04-140-FY09 | 144 | 1,064 | 42,804 | Shear |
| MAT2-SXZ-05-140-FY09 | 128 | 949 | 39,588 | Shear |
| Average | 135 | 1,019 | 43,716 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets E-104 to E-108
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-01-140-FY09**
 Test Date: 8/09/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

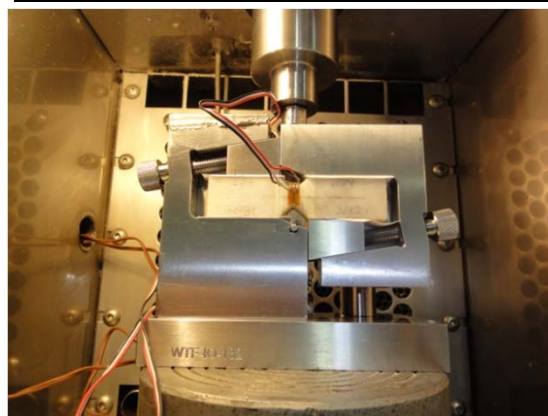
Average Material Properties:

Ultimate Load, P_{max} : 136 lbs
Shear Strength, S_{xz} : 1,017 psi
Shear Modulus, G_{xz} : 43,142 psi

Measured Specimen Dimensions:

Depth, D: 0.488 in
 Notch Length, NL: 0.275 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 68 lbs
 20% Max Load: 27 lbs

PICTURE OF SPECIMEN PRE-TEST



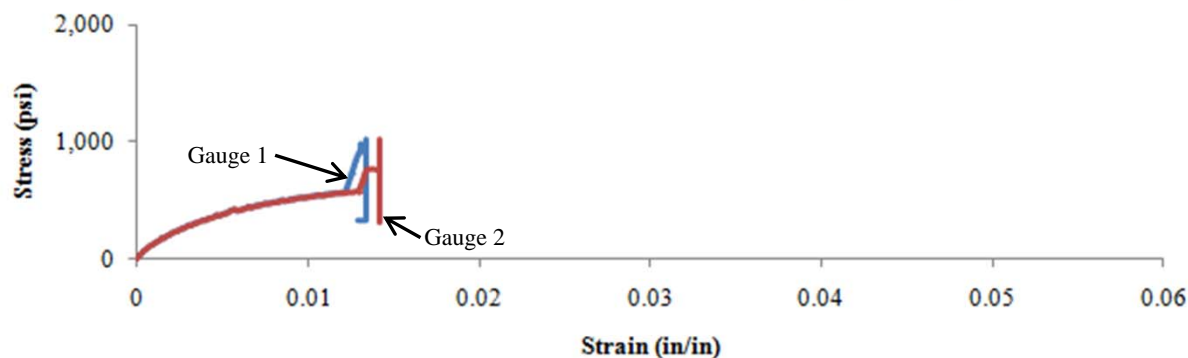
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0089 | 0.0019 | 43,333 |
| 2 | 0.0090 | 0.0019 | 42,950 |
| Average | | | 43,142 |

Stress-Strain Curve 140°F_01_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-02-140-FY09**
 Test Date: 8/09/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 137 lbs
Shear Strength, S_{xz} : 1,009 psi
Shear Modulus, G_{xz} : 40,006 psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.273 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 69 lbs
 20% Max Load: 27 lbs

PICTURE OF SPECIMEN PRE-TEST



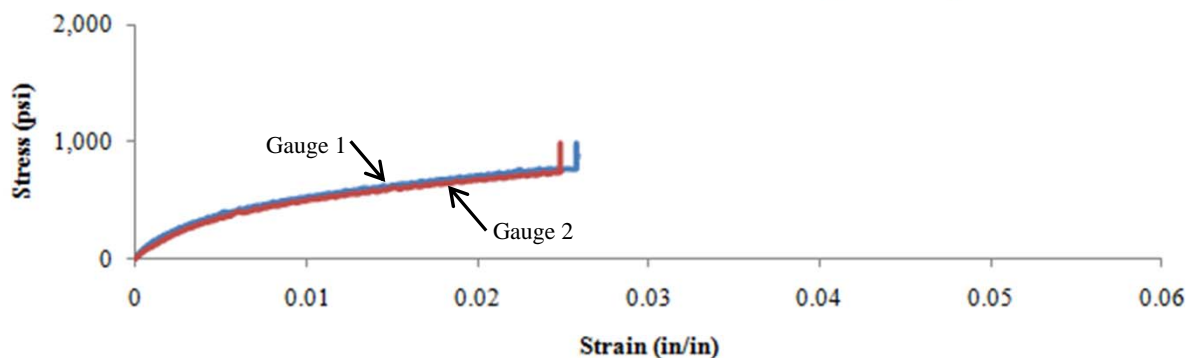
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0088 | 0.0016 | 41,980 |
| 2 | 0.0101 | 0.0021 | 38,032 |
| Average | | | 40,006 |

Stress-Strain Curve 140°F_02_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-03-140-FY09**
 Test Date: 8/10/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **129** lbs
 Shear Strength, S_{xz} : **1,055** psi
 Shear Modulus, G_{xz} : **53,042** psi

Measured Specimen Dimensions:

Depth, D: 0.449 in
 Notch Length, NL: 0.273 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 65 lbs
 20% Max Load: 26 lbs

PICTURE OF SPECIMEN PRE-TEST



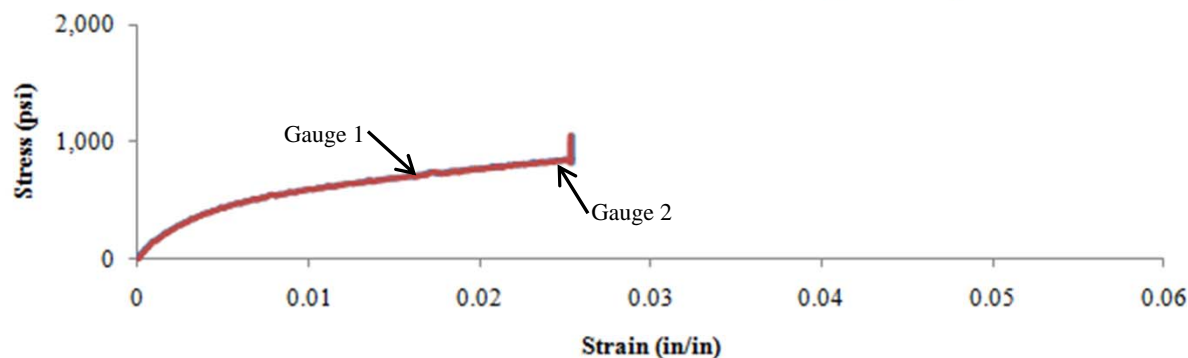
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0075 | 0.0015 | 53,202 |
| 2 | 0.0075 | 0.0015 | 52,883 |
| Average | | | 53,042 |

Stress-Strain Curve 140°F_03_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-04-140-FY09**
 Test Date: 8/10/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **144** **lbs**
Shear Strength, S_{xz} : **1,064** **psi**
Shear Modulus, G_{xz} : **42,804** **psi**

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.273 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 72 lbs
 20% Max Load: 29 lbs

PICTURE OF SPECIMEN PRE-TEST



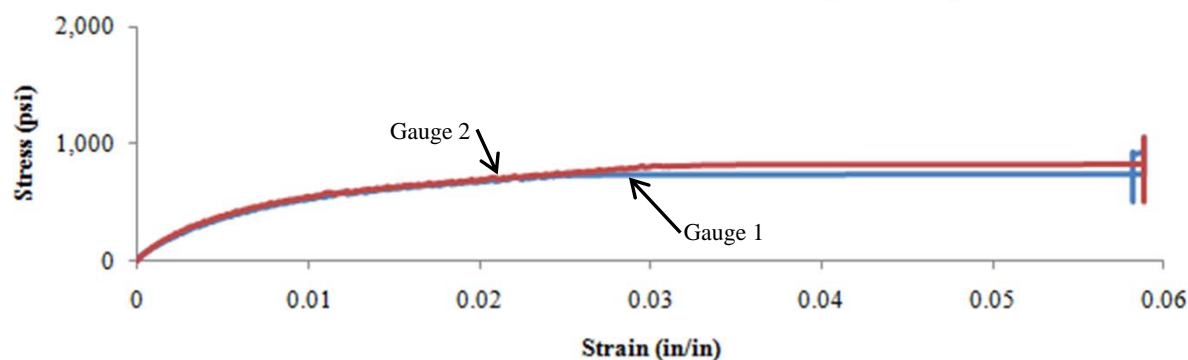
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0100 | 0.0023 | 41,512 |
| 2 | 0.0093 | 0.0020 | 44,096 |
| Average | | | 42,804 |

Stress-Strain Curve 140°F_04_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT2-SXZ-05-140-FY09**
 Test Date: 8/12/11
 Specimen Received: 5/20/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **128** lbs
 Shear Strength, S_{xz} : **949** psi
 Shear Modulus, G_{xz} : **39,588** psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.272 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 64 lbs
 20% Max Load: 26 lbs

PICTURE OF SPECIMEN PRE-TEST



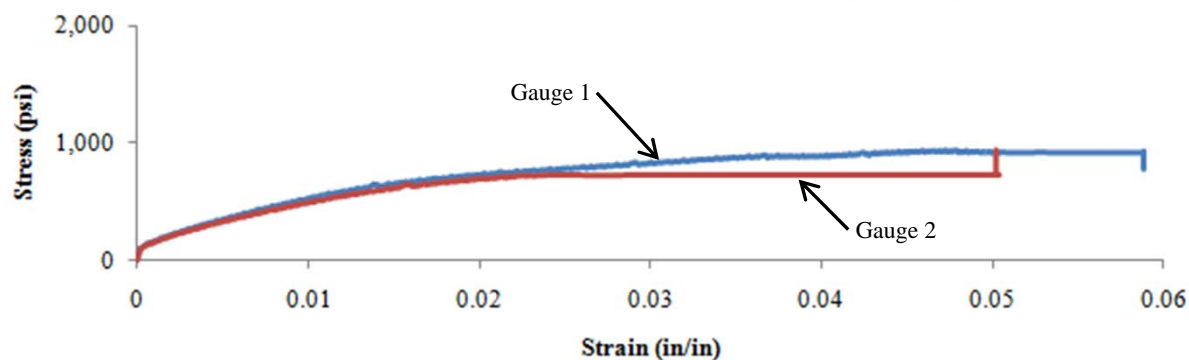
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0094 | 0.0026 | 41,833 |
| 2 | 0.0105 | 0.0028 | 37,342 |
| Average | | | 39,588 |

Stress-Strain Curve 140°F_05_(09-02)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

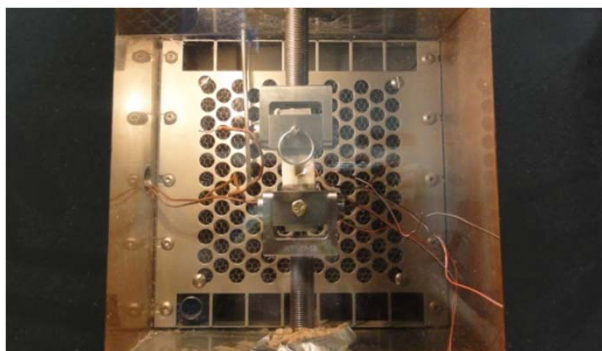
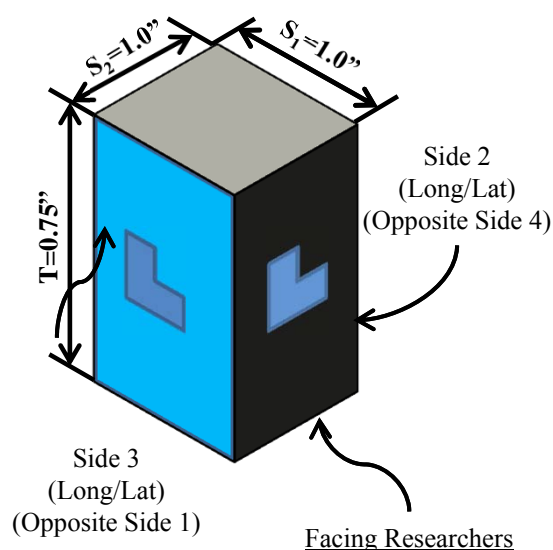
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-OP-N40-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1526
 Maximum Load, P_z : 4,755 lbs

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|---------------------|----------------------|-----------------------------|--------------|
| 1 | MAT2-OP-01-N40-FY09 | 4,940 | 0.1496 | Rupture |
| 2 | MAT2-OP-02-N40-FY09 | 4,674 | 0.1557 | Rupture |
| 3 | MAT2-OP-03-N40-FY09 | 4,613 | 0.1664 | Rupture |
| 4 | MAT2-OP-04-N40-FY09 | 4,896 | 0.1440 | Rupture |
| 5 | MAT2-OP-05-N40-FY09 | 4,652 | 0.1474 | Rupture |
| Average | | 4,755 | 0.1526 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The blocks nominal dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference E-110 thru E-114 for individual specimen data.
- 2) 7 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-01-N40-FY09**
 Test Date: 5/13/2011
 Specimen Received: 4/22/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,940 lbs
 Poisson's Ratio, v_{xz} : 0.1496

Measured Specimen Dimensions:

Thickness: 0.775 in
 Side 1: 0.994 in
 Side 2: 0.991 in

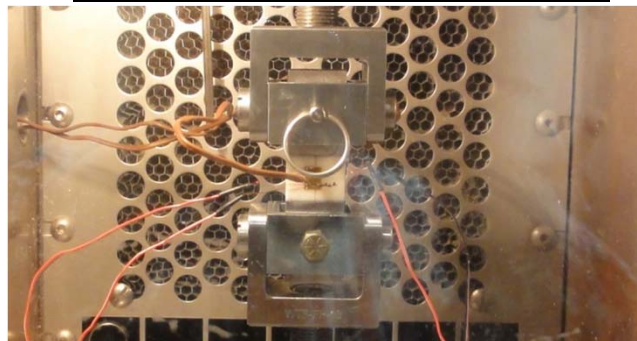
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,470 lbs

20% Max Load: 988 lbs

PICTURE OF SPECIMEN PRE-TEST



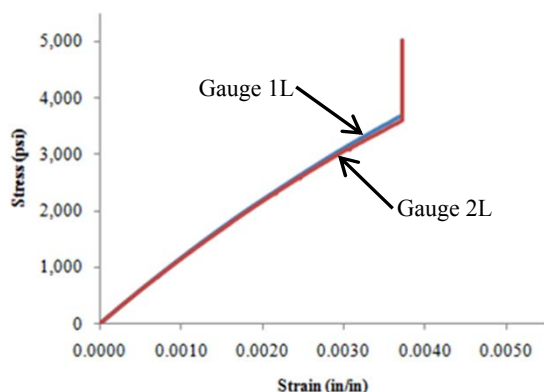
PICTURE OF SPECIMEN POST-TEST



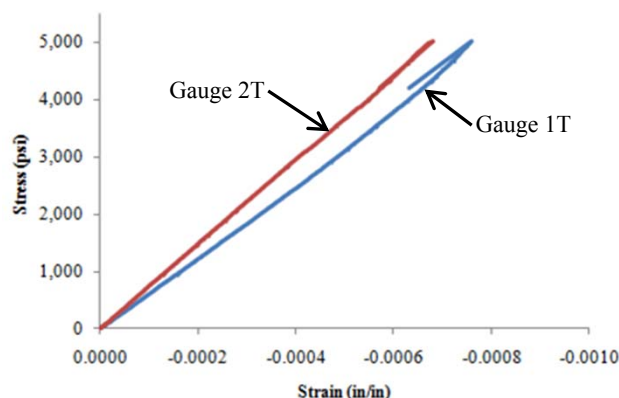
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002329 | 0.000849 | 1T | -0.000411 | -0.000167 | 0.1644 |
| 2L | 0.002364 | 0.000862 | 2T | -0.000339 | -0.000137 | 0.1348 |
| Average | | | | | | 0.1496 |

Stress-Strain Curve_N40_1_(09-02)_Long



Stress-Strain Curve_N40_1_(09-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-02-N40-FY09**
 Test Date: 5/16/2011
 Specimen Received: 4/22/2011
 Properties Measured: v_{xz}

Average Material Properties:

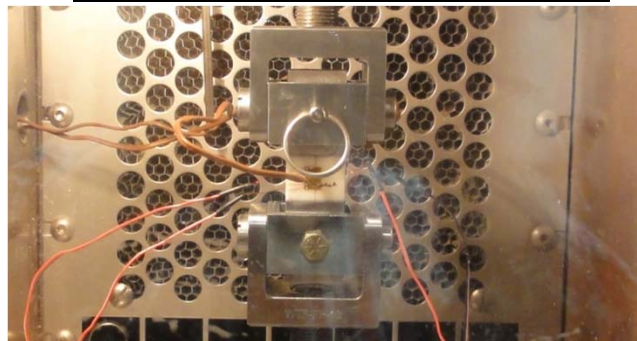
Maximum Load, P_z : 4,674 lbs
 Poisson's Ratio, v_{xz} : 0.1557

Measured Specimen Dimensions:

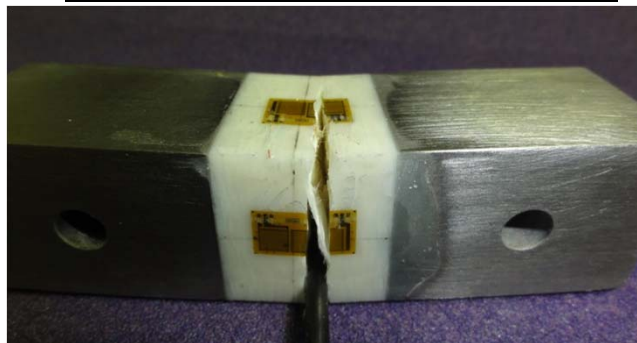
Thickness: 0.768 in
 Side 1: 0.982 in
 Side 2: 0.985 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,337 lbs
 20% Max Load: 935 lbs

PICTURE OF SPECIMEN PRE-TEST



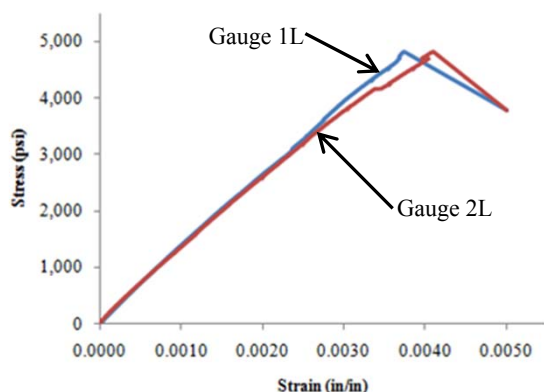
PICTURE OF SPECIMEN POST-TEST



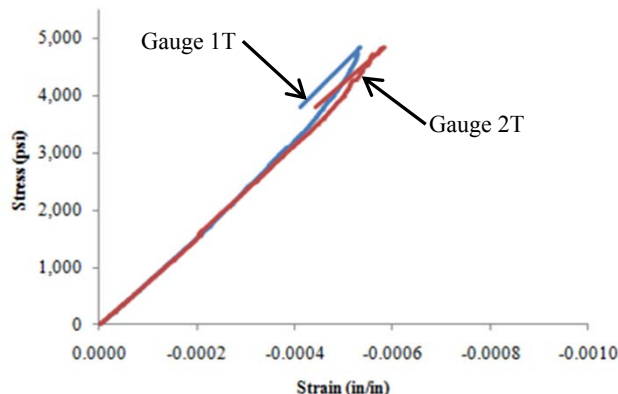
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001806 | 0.000674 | 1T | -0.000305 | -0.000129 | 0.1557 |
| 2L | 0.001841 | 0.000691 | 2T | -0.000310 | -0.000131 | 0.1557 |
| Average | | | | | | 0.1557 |

Stress-Strain Curve_N40_2_(09-02)_Long



Stress-Strain Curve_N40_2_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-03-N40-FY09**
 Test Date: 5/16/2011
 Specimen Received: 4/22/2011
 Properties Measured: v_{xz}

Average Material Properties:

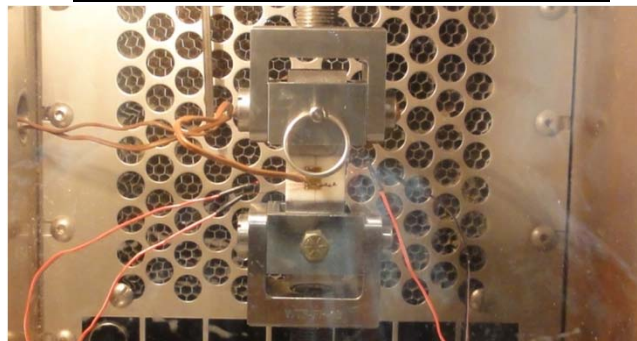
Maximum Load, P_z : 4,613 lbs
 Poisson's Ratio, v_{xz} : 0.1664

Measured Specimen Dimensions:

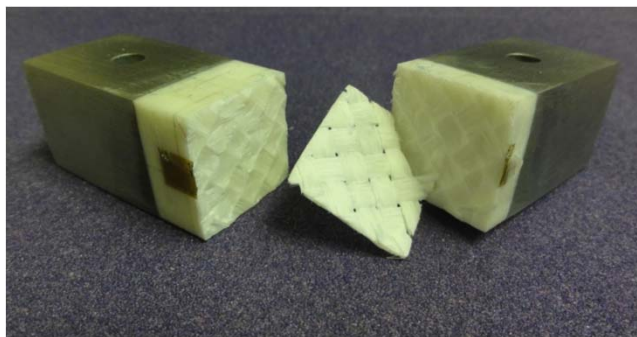
Thickness: 0.770 in
 Side 1: 0.986 in
 Side 2: 0.986 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,307 lbs
 20% Max Load: 923 lbs

PICTURE OF SPECIMEN PRE-TEST



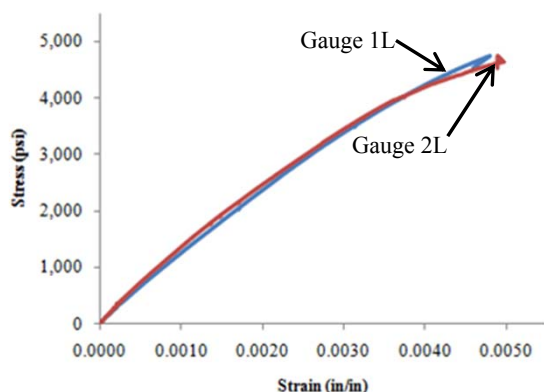
PICTURE OF SPECIMEN POST-TEST



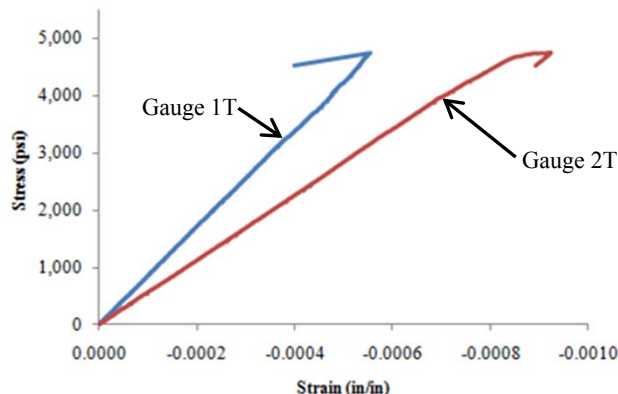
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001999 | 0.000732 | 1T | -0.000281 | -0.000114 | 0.1315 |
| 2L | 0.001906 | 0.000665 | 2T | -0.000421 | -0.000171 | 0.2013 |
| Average | | | | | | 0.1664 |

Stress-Strain Curve_N40_3_(09-02)_Long



Stress-Strain Curve_N40_3_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-04-N40-FY09**
 Test Date: 5/17/2011
 Specimen Received: 4/22/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,896 lbs
 Poisson's Ratio, v_{xz} : 0.1440

Measured Specimen Dimensions:

Thickness: 0.765 in
 Side 1: 0.981 in
 Side 2: 0.986 in

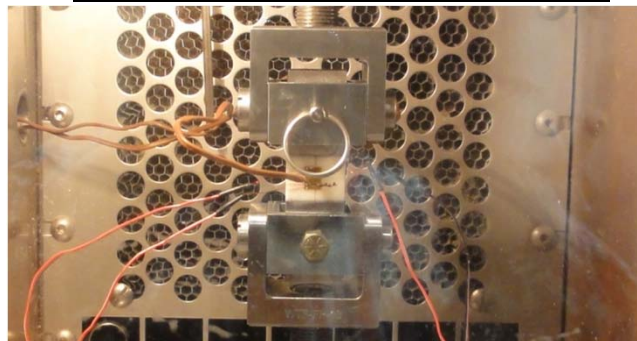
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,448 lbs

20% Max Load: 979 lbs

PICTURE OF SPECIMEN PRE-TEST



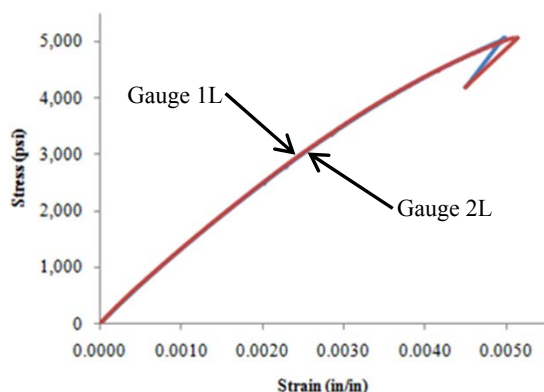
PICTURE OF SPECIMEN POST-TEST



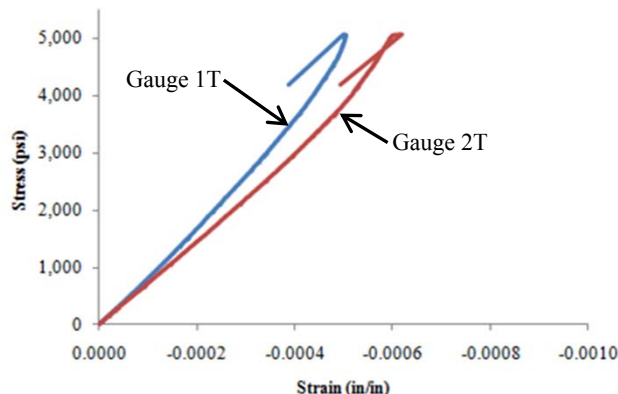
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002047 | 0.000750 | 1T | -0.000294 | -0.000125 | 0.1300 |
| 2L | 0.002036 | 0.000743 | 2T | -0.000345 | -0.000141 | 0.1580 |
| Average | | | | | | 0.1440 |

Stress-Strain Curve_N40_4_(09-02)_Long



Stress-Strain Curve_N40_4_(09-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-05-N40-FY09**
 Test Date: 5/17/2011
 Specimen Received: 4/22/2011
 Properties Measured: v_{xz}

Average Material Properties:

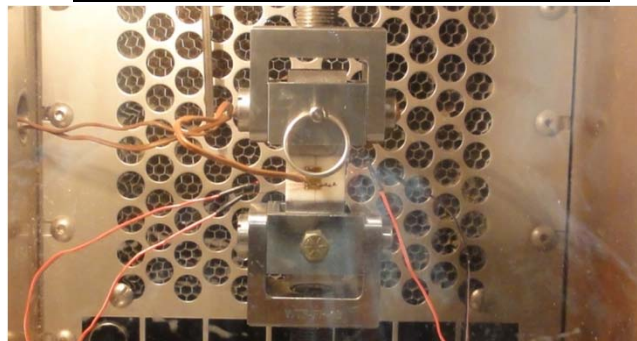
Maximum Load, P_z : 4,652 lbs
 Poisson's Ratio, v_{xz} : 0.1474

Measured Specimen Dimensions:

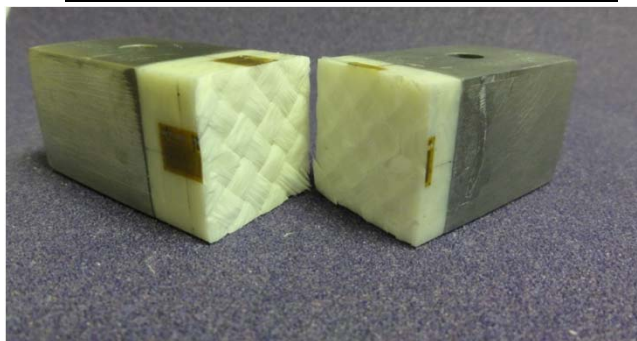
Thickness: 0.759 in
 Side 1: 0.980 in
 Side 2: 0.986 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,326 lbs
 20% Max Load: 930 lbs

PICTURE OF SPECIMEN PRE-TEST



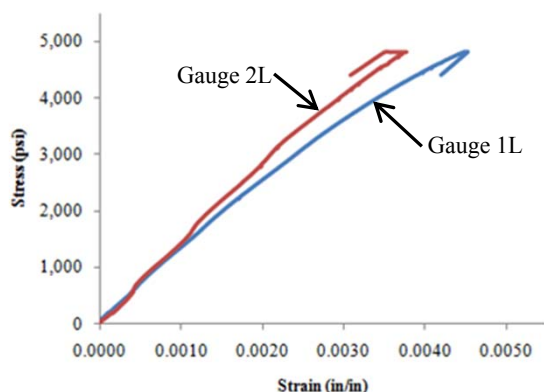
PICTURE OF SPECIMEN POST-TEST



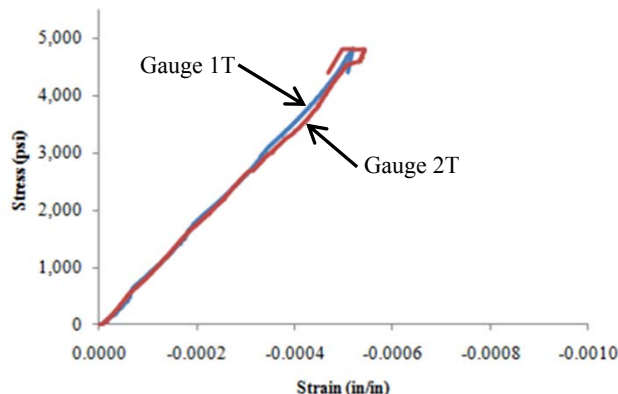
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001876 | 0.000681 | 1T | -0.000276 | -0.000110 | 0.1385 |
| 2L | 0.001686 | 0.000642 | 2T | -0.000276 | -0.000113 | 0.1562 |
| Average | | | | | | 0.1474 |

Stress-Strain Curve_N40_5_(09-02)_Long



Stress-Strain Curve_N40_5_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT2-OP-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass

Nominal Temperature: 70°F

Properties Measured:

Average Material Properties (5 Specimens):

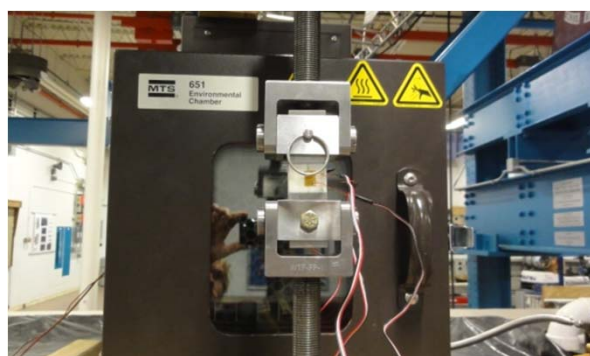
Poisson’s Ratio, ν_{xz} : 0.1741

Maximum Load, P_z : 3,100 lbs

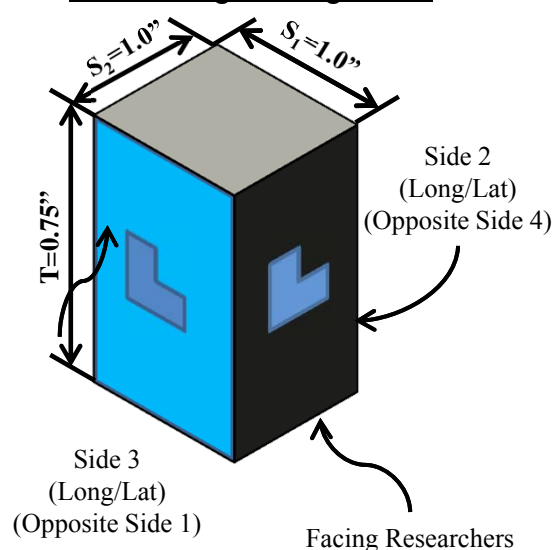
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|----------------------|-----------------------------|--------------|
| 1 | MAT2-OP-01-70-FY09 | 2,652 | 0.1655 | Rupture |
| 2 | MAT2-OP-02-70-FY09 | 2,749 | 0.1947 | Rupture |
| 3 | MAT2-OP-03-70-FY09 | 3,018 | 0.1436 | Rupture |
| 4 | MAT2-OP-04-70-FY09 | 3,594 | 0.1431 | Rupture |
| 5 | MAT2-OP-05-70-FY09 | 3,487 | 0.2235 | Rupture |
| Average | | 3,100 | 0.1741 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) Reference E-116 thru E-120 for individual specimen data.
- 2) 10 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-01-70-FY09**
 Test Date: 5/2/2011
 Specimen Received: 4/19/2011
 Properties Measured: v_{xz}

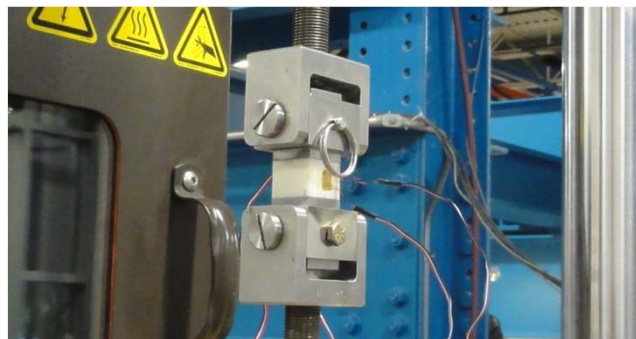
Average Material Properties:

Maximum Load, P_z : 2,652 lbs
 Poisson's Ratio, v_{xz} : 0.1655

Measured Specimen Dimensions:

Thickness: 0.761 in
 Side 1: 0.987 in
 Side 2: 0.991 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,326 lbs
 20% Max Load: 530 lbs

PICTURE OF SPECIMEN PRE-TEST

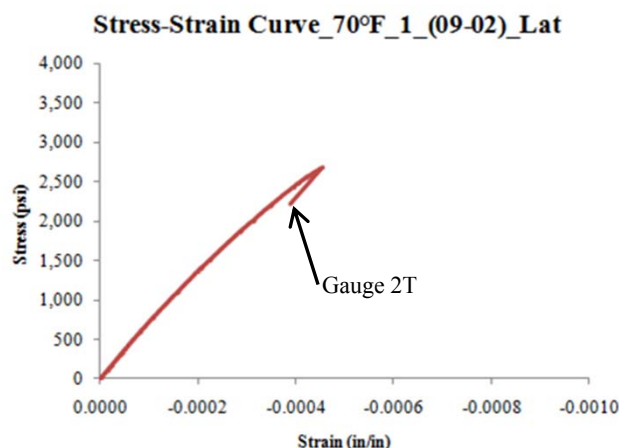
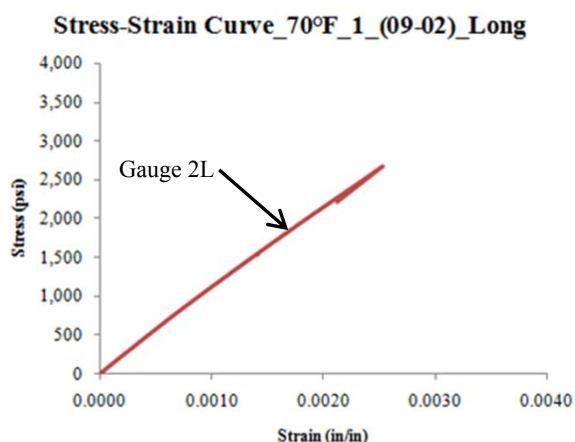


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | Lost Gauge | Lost Gauge | 1T | Lost Gauge | Lost Gauge | - |
| 2L | 0.001236 | 0.000472 | 2T | -0.000199 | -0.000073 | 0.1655 |
| Average | | | | | | 0.1655 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-02-70-FY09**
 Test Date: 5/2/2011
 Specimen Received: 4/19/2011
 Properties Measured: v_{xz}

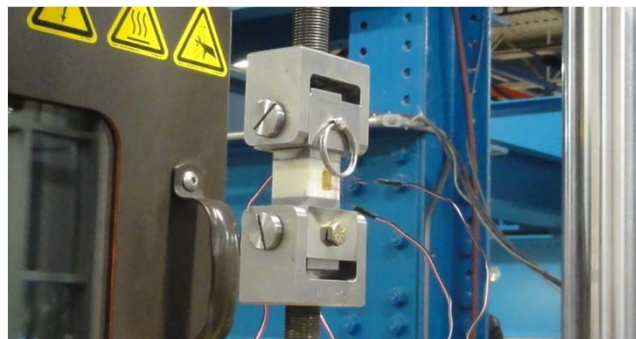
Average Material Properties:

Maximum Load, P_z : 2,749 lbs
 Poisson's Ratio, v_{xz} : 0.1947

Measured Specimen Dimensions:

Thickness: 0.757 in
 Side 1: 0.996 in
 Side 2: 0.990 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,375 lbs
 20% Max Load: 550 lbs

PICTURE OF SPECIMEN PRE-TEST

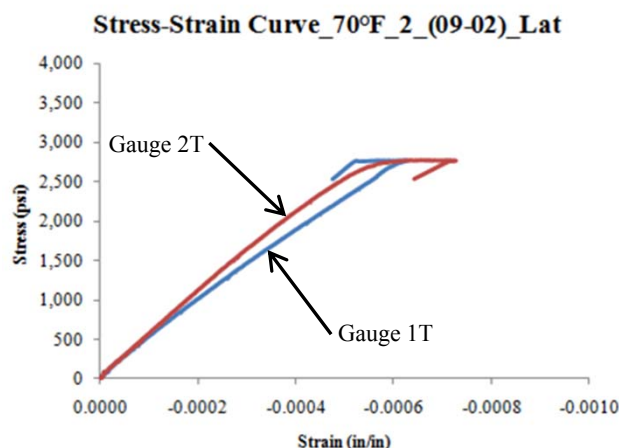
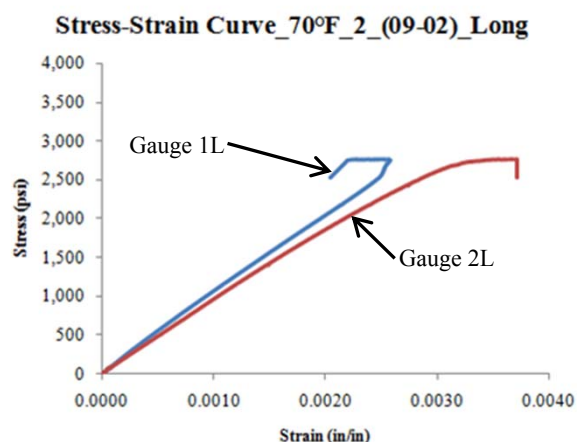


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001321 | 0.000502 | 1T | -0.000282 | -0.000104 | 0.2170 |
| 2L | 0.001456 | 0.000576 | 2T | -0.000249 | -0.000097 | 0.1724 |
| Average | | | | | | 0.1947 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-03-70-FY09**
 Test Date: 5/4/2011
 Specimen Received: 4/19/2011
 Properties Measured: v_{xz}

Average Material Properties:

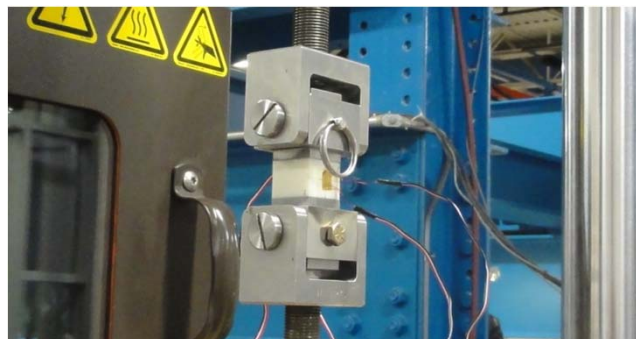
Maximum Load, P_z : 3,018 lbs
 Poisson's Ratio, v_{xz} : 0.1436

Measured Specimen Dimensions:

Thickness: 0.759 in
 Side 1: 0.989 in
 Side 2: 0.985 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,509 lbs
 20% Max Load: 604 lbs

PICTURE OF SPECIMEN PRE-TEST

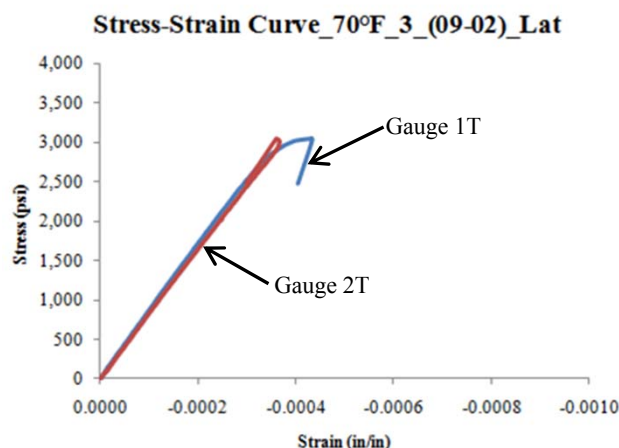
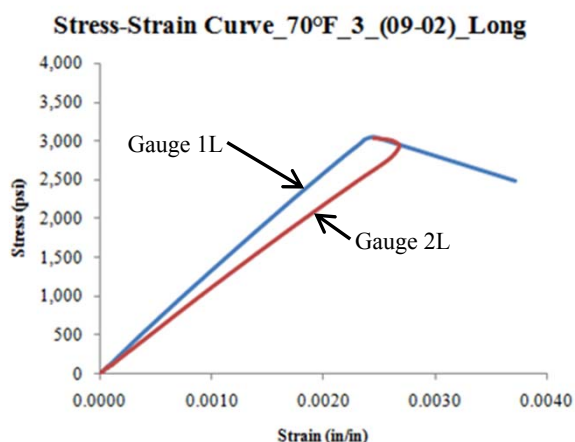


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001151 | 0.000448 | 1T | -0.000177 | -0.000069 | 0.1526 |
| 2L | 0.001374 | 0.000545 | 2T | -0.000185 | -0.000073 | 0.1346 |
| Average | | | | | | 0.1436 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-04-70-FY09**
 Test Date: 5/6/2011
 Specimen Received: 4/19/2011
 Properties Measured: v_{xz}

Average Material Properties:

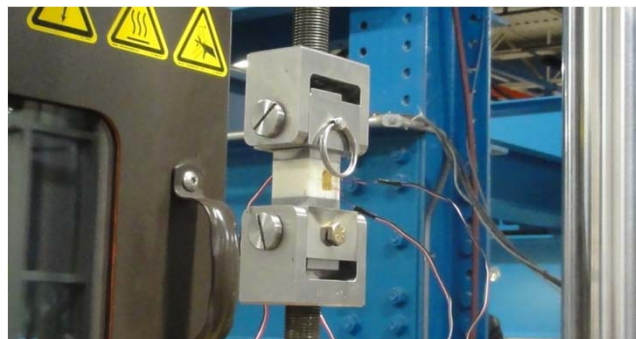
Maximum Load, P_z : 3,594 lbs
 Poisson's Ratio, v_{xz} : 0.1431

Measured Specimen Dimensions:

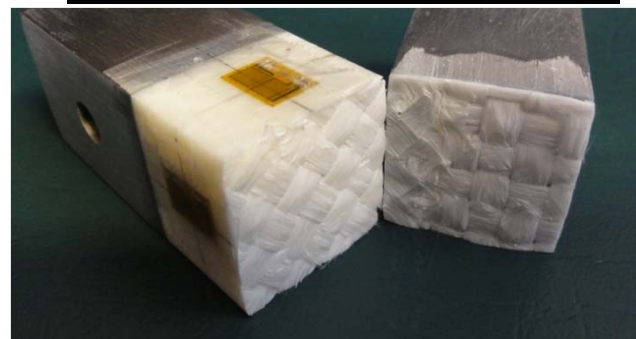
Thickness: 0.765 in
 Side 1: 0.994 in
 Side 2: 0.991 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,797 lbs
 20% Max Load: 719 lbs

PICTURE OF SPECIMEN PRE-TEST

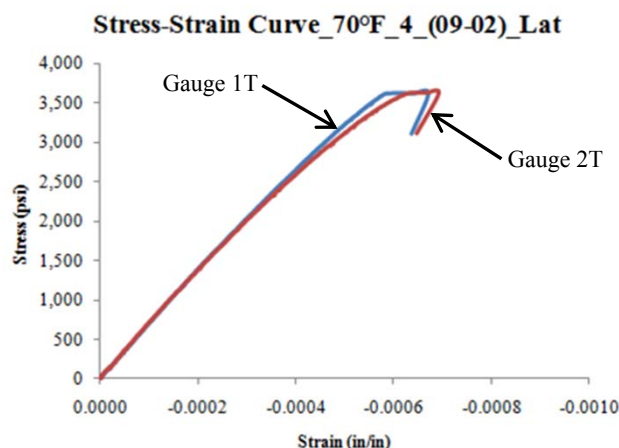
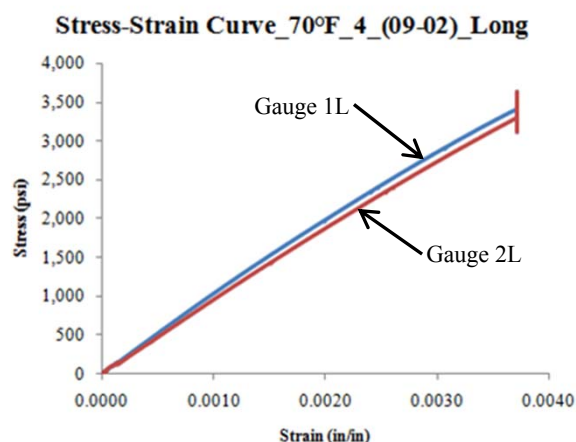


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001817 | 0.000696 | 1T | -0.000266 | -0.000104 | 0.1445 |
| 2L | 0.001935 | 0.000761 | 2T | -0.000269 | -0.000103 | 0.1416 |
| Average | | | | | | 0.1431 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-05-70-FY09**
 Test Date: 5/6/2011
 Specimen Received: 4/19/2011
 Properties Measured: v_{xz}

Average Material Properties:

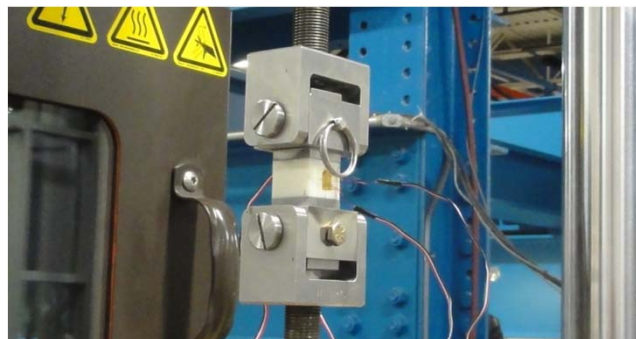
Maximum Load, P_z : 3,487 lbs
 Poisson's Ratio, v_{xz} : 0.2235

Measured Specimen Dimensions:

Thickness: 0.767 in
 Side 1: 0.994 in
 Side 2: 0.990 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,744 lbs
 20% Max Load: 697 lbs

PICTURE OF SPECIMEN PRE-TEST

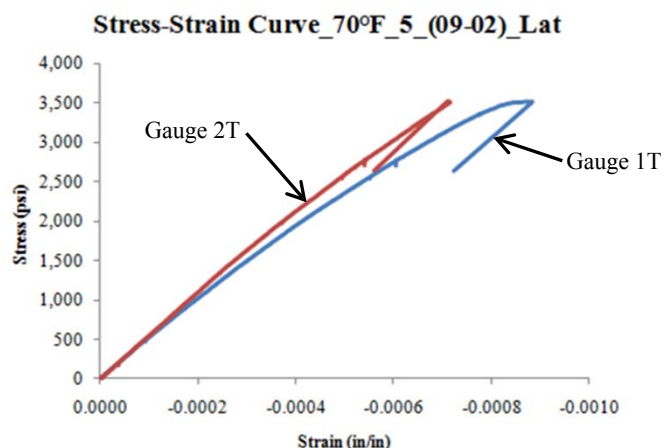
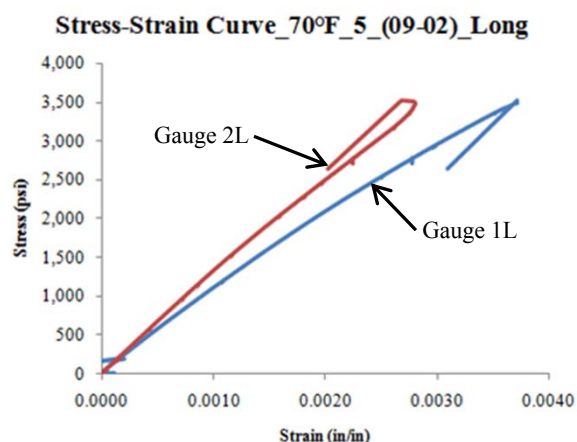


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001652 | 0.000615 | 1T | -0.000358 | -0.000137 | 0.2134 |
| 2L | 0.001350 | 0.000514 | 2T | -0.000326 | -0.000131 | 0.2336 |
| Average | | | | | | 0.2235 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

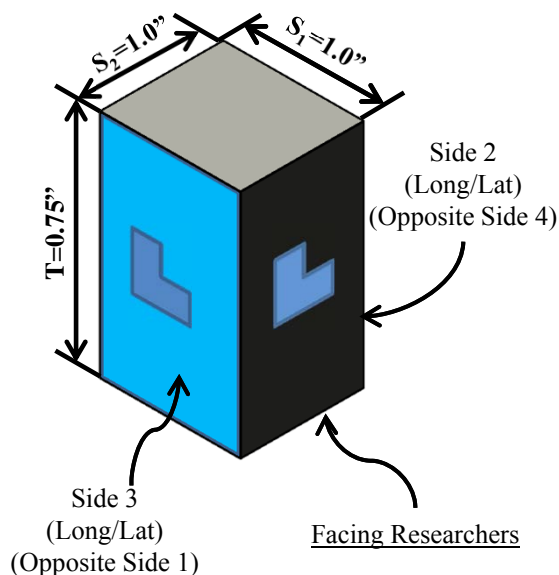
TEST SUMMARY/RESULTS –AVERAGE OF 4 SPECIMENS

Specimen ID Group: **MAT2-OP-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.1365**
 Maximum Load, P_z : **1,587 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|----------------------|-----------------------------|--------------|
| 1 | MAT2-OP-1-140-FY09 | 1,589 | 0.1611 | Bondline |
| 2 | MAT2-OP-2-140-FY09 | 1,589 | 0.0506 | Bondline |
| 3 | MAT2-OP-3-140-FY09 | 1,578 | 0.1970 | Bondline |
| 4 | MAT2-OP-4-140-FY09 | 1,580 | 0.1196 | Bondline |
| Average | | 1,584 | 0.1321 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference D-122 thru D-126 for individual specimen data.
- 2) 6 specimens tested, group of 4 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-1-140-FY09**
 Test Date: 5/22/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,589 lbs
 Poisson's Ratio, v_{xz} : 0.1611

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.994 in

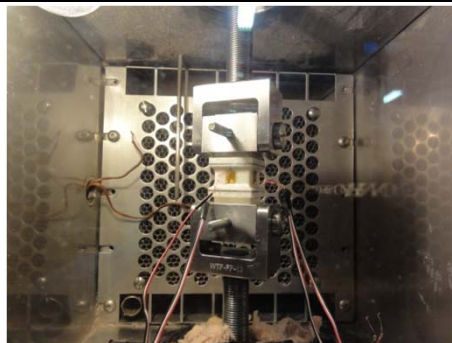
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 795 lbs

20% Max Load: 318 lbs

PICTURE OF SPECIMEN PRE-TEST



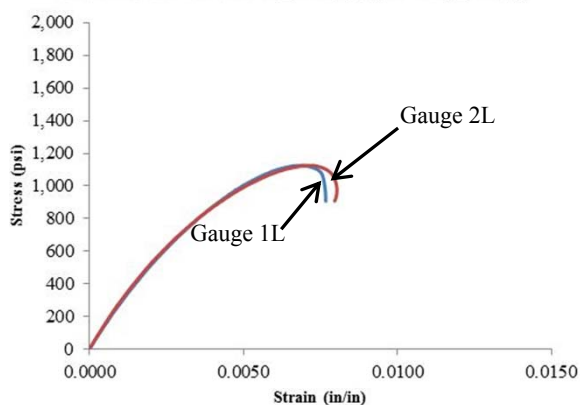
PICTURE OF SPECIMEN POST-TEST



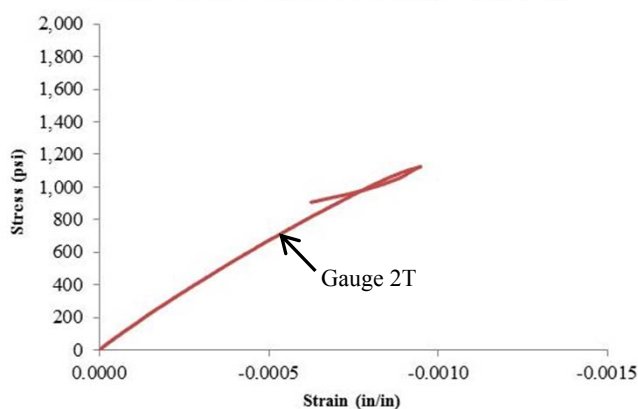
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003530 | 0.001148 | 1T | Lost Gauge | | 0.1611 |
| 2L | 0.003528 | 0.001103 | 2T | -0.000610 | -0.000219 | |
| Average | | | | | | 0.1611 |

Stress-Strain Curve_140_1_(09-02)_Long



Stress-Strain Curve_140_1_(09-02)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-2-140-FY09**
 Test Date: 5/22/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

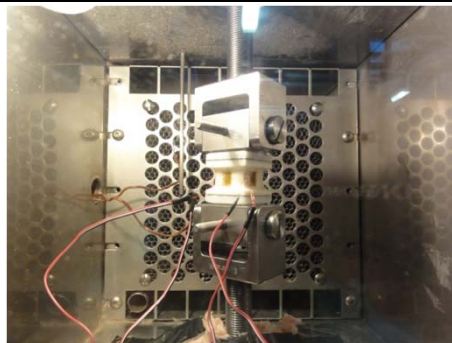
Maximum Load, P_z : 1,589 lbs
 Poisson's Ratio, v_{xz} : 0.0506

Measured Specimen Dimensions:

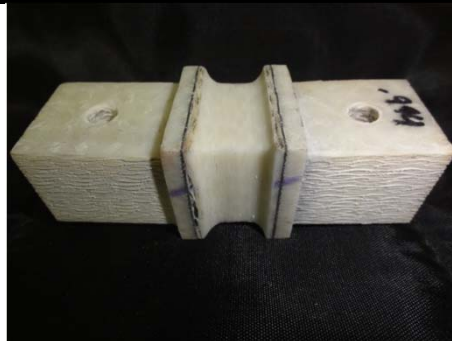
Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.994 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 795 lbs
 20% Max Load: 318 lbs

PICTURE OF SPECIMEN PRE-TEST



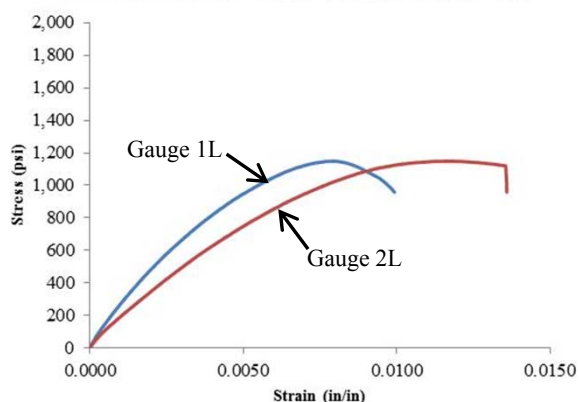
PICTURE OF SPECIMEN POST-TEST



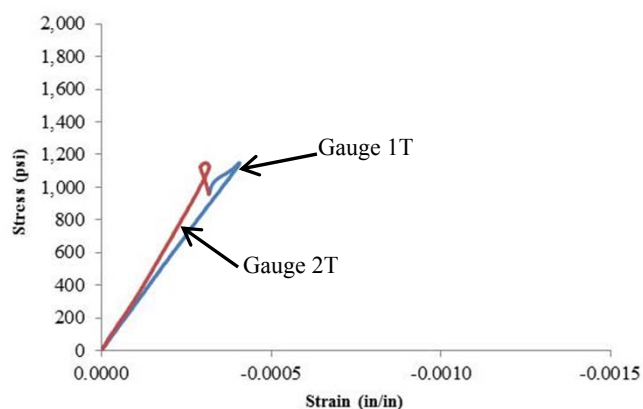
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003868 | 0.001212 | 1T | -0.000282 | -0.000111 | 0.0641 |
| 2L | 0.005477 | 0.001811 | 2T | -0.000236 | -0.000099 | 0.0372 |
| Average | | | | | | 0.0506 |

Stress-Strain Curve_140_2_(09-02)_Long



Stress-Strain Curve_140_2_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-3-140-FY09**
 Test Date: 5/22/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 1,578 lbs
 Poisson's Ratio, v_{xz} : 0.1970

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.995 in
 Side 2: 0.990 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 789 lbs
 20% Max Load: 316 lbs

PICTURE OF SPECIMEN PRE-TEST



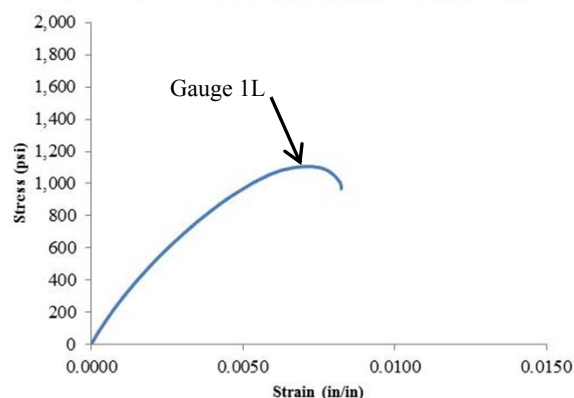
PICTURE OF SPECIMEN POST-TEST



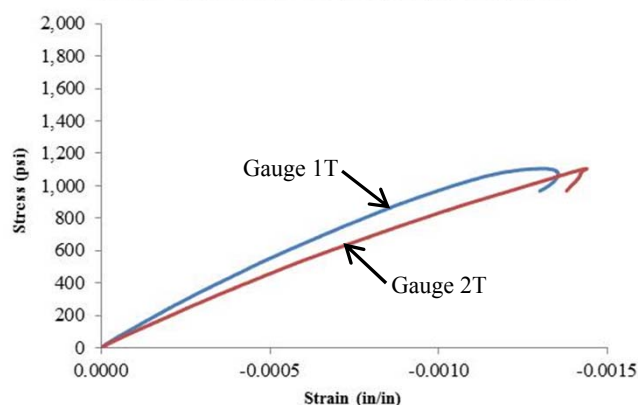
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.003744 | 0.001158 | 1T | -0.000779 | -0.000270 | 0.1970 |
| 2L | Lost Gauge | | 2T | -0.000955 | -0.000338 | LG |
| Average | | | | | | 0.1970 |

Stress-Strain Curve_140_3_(09-02)_Long



Stress-Strain Curve_140_3_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT2-OP-4-140-FY09**
 Test Date: 5/23/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz}

Average Material Properties:

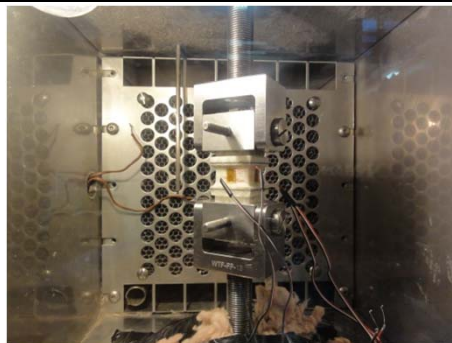
Maximum Load, P_z : 1,580 lbs
 Poisson's Ratio, v_{xz} : 0.1196

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.996 in
 Side 2: 0.990 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 790 lbs
 20% Max Load: 316 lbs

PICTURE OF SPECIMEN PRE-TEST



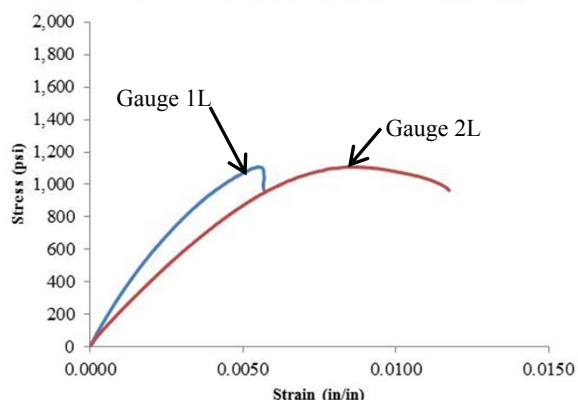
PICTURE OF SPECIMEN POST-TEST



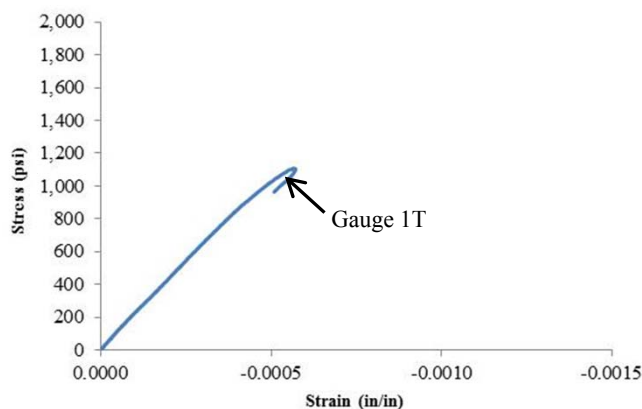
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002285 | 0.000707 | 1T | -0.000293 | -0.000104 | 0.1196 |
| 2L | 0.003371 | 0.001085 | 2T | Lost Gauge | | |
| Average | | | | | | 0.1196 |

Stress-Strain Curve_140_4_(09-02)_Long



Stress-Strain Curve_140_4_(09-02)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

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APPENDIX F

MATERIAL 3-FY09 TESTING RESULTS

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MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

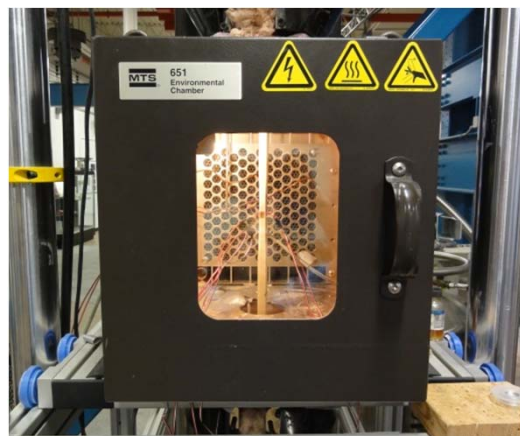
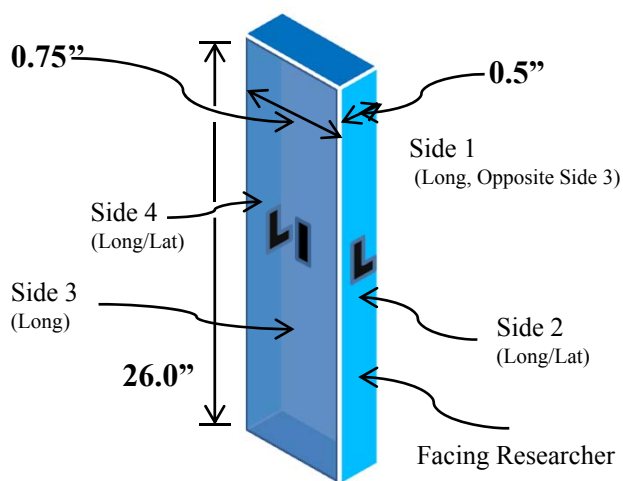
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-TX-N40-FY09
 Material: 3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers
 Nominal Temperature: -40°F
 Properties Measured: ST_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 25,110 lbs
 Tensile Strength, ST_x : 94,461 psi
 Tensile Modulus, E_x : 2,923,745 psi
 Ultimate Strain, ϵ_x : 0.0329 in/in
 Poisson's Ratio, ν_{xy} : 0.0699

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT3-TX-1-N40-FY09 | 24,978 | 93,988 | 3,045,252 | 0.0309 | 0.0658 | LGM |
| 2 | MAT3-TX-2-N40-FY09 | 26,826 | 93,589 | 3,076,816 | 0.0304 | 0.0642 | LGM |
| 3 | MAT3-TX-3-N40-FY09 | 27,025 | 95,855 | 2,536,132 | 0.0378 | 0.0574 | LGM |
| 4 | MAT3-TX-4-N40-FY09 | 23,540 | 91,772 | 2,898,267 | 0.0317 | 0.0634 | LGM |
| 5 | MAT3-TX-5-N40-FY09 | 23,180 | 97,100 | 3,062,260 | 0.0317 | 0.0947 | LGM |
| Average | | 25,110 | 94,461 | 2,923,745 | 0.0329 | 0.0699 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. In this test, load is applied within this fiber plane. Aramid fibers also exist in the "z" direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint is used to eliminate all moments about the fixed lower head and allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 7 specimens tested, group of 5 displayed with relevant data shown
- 2) LGM corresponds with L=lateral, G=gauge area, M=middle of specimen
- 3) See F-2 to F-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-35% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-1-N40-FY09**
 Test Date: 1/19/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 24,978 lbs
 Tensile Strength, ST_x : 93,988 psi
 Tensile Modulus, E_x : 3,045,252 psi
 Ultimate Strain, ϵ_x : 0.0309 in/in
 Poisson's Ratio, v_{xy} : 0.0658

Measured Specimen Dimensions:

Width, W: 0.3660 in
 Thickness, H: 0.7261 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 10% Max Load: 2,498 lbs
 35% Max Load: 8,742 lbs

PICTURE OF SPECIMEN PRE-TEST



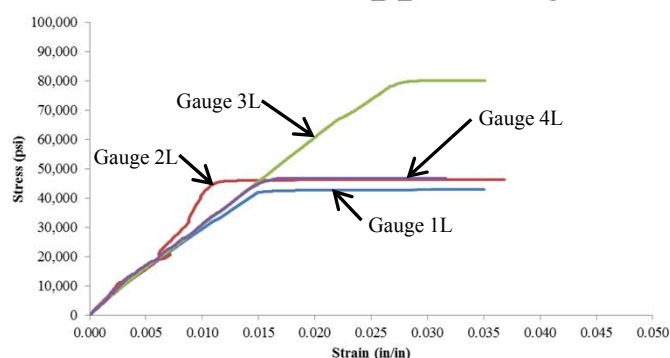
PICTURE OF SPECIMEN POST-TEST



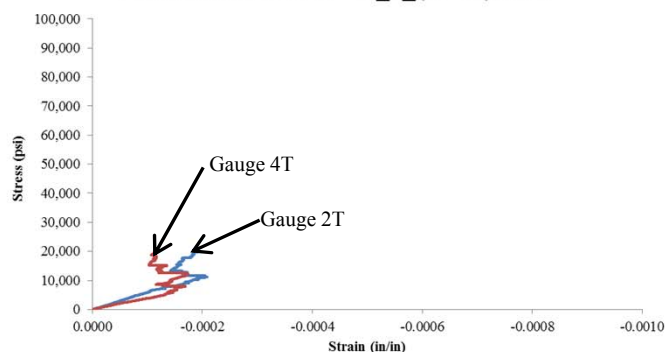
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 35% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0114 | 0.0027 | 2,697,646 | | | | |
| 2L | 0.0088 | 0.0023 | 3,584,154 | 2T | -0.0002 | 0.0000 | 0.0759 |
| 3L | 0.0107 | 0.0028 | 2,983,901 | | | | |
| 4L | 0.0106 | 0.0025 | 2,915,306 | 4T | -0.0001 | 0.0000 | 0.0558 |
| Average | | | 3,045,252 | | | | 0.0658 |

Stress-Strain Curve -40_1_(09-03), Long.



Stress-Strain Curve -40_1_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 10% and 35% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-2-N40-FY09**
 Test Date: 1/19/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 26,826 lbs
 Tensile Strength, ST_x : 93,589 psi
 Tensile Modulus, E_x : 3,076,816 psi
 Ultimate Strain, ϵ_x : 0.0304 in/in
 Poisson's Ratio, v_{xy} : 0.0642

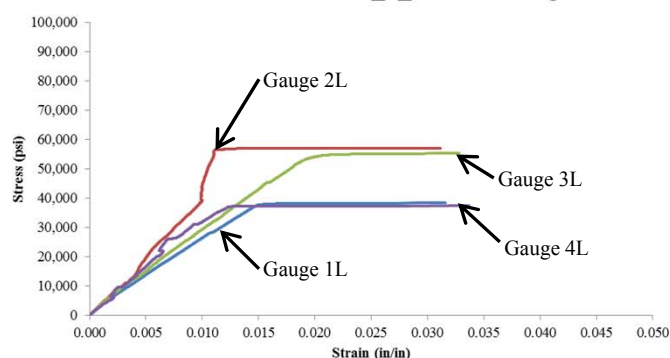
Measured Specimen Dimensions:

Width, W: 0.3689 in
 Thickness, H: 0.7770 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 10% Max Load: 2,683 lbs
 35% Max Load: 9,389 lbs

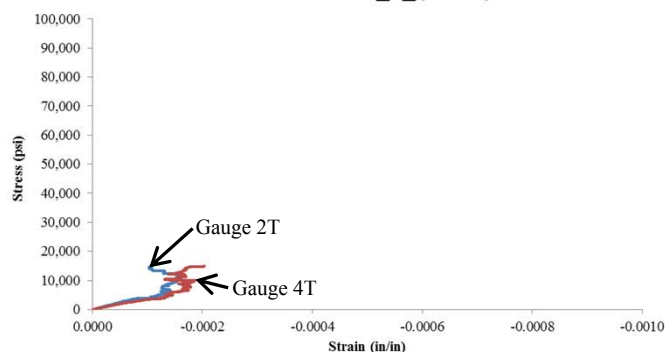
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 35% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0128 | 0.0033 | 2,455,708 | | | | |
| 2L | 0.0083 | 0.0027 | 4,172,396 | 2T | -0.0001 | 0.0000 | 0.0552 |
| 3L | 0.0113 | 0.0028 | 2,727,697 | | | | |
| 4L | 0.0104 | 0.0024 | 2,951,464 | 4T | -0.0002 | 0.0000 | 0.0733 |
| Average | | | 3,076,816 | | | | 0.0642 |

Stress-Strain Curve -40_2_(09-03), Long.



Stress-Strain Curve -40_2_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 10% and 35% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-3-N40-FY09**
 Test Date: 1/19/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 27,025 lbs
 Tensile Strength, ST_x : 95,855 psi
 Tensile Modulus, E_x : 2,536,132 psi
 Ultimate Strain, ϵ_x : 0.0378 in/in
 Poisson's Ratio, v_{xy} : 0.0574

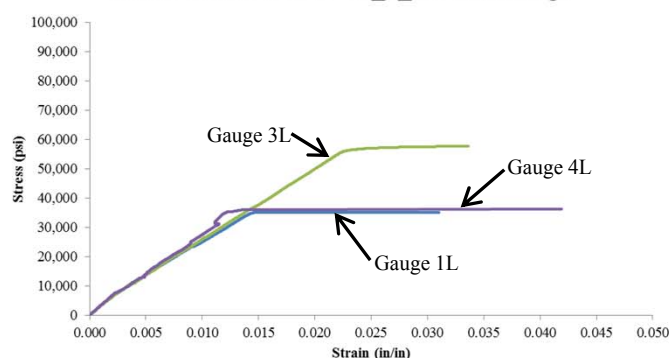
Measured Specimen Dimensions:

Width, W: 0.3645 in
 Thickness, H: 0.7735 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 10% Max Load: 2,703 lbs
 35% Max Load: 9,459 lbs

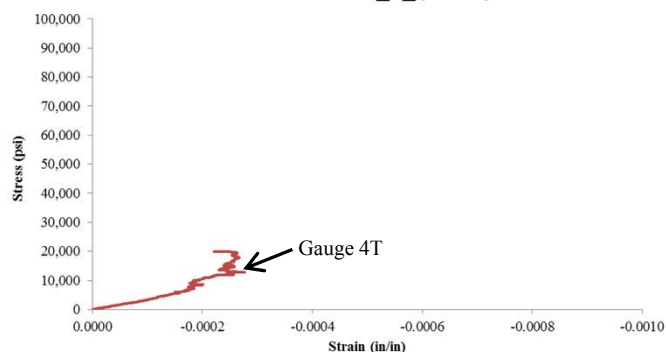
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 35% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0137 | 0.0033 | 2,300,277 | | | | |
| 2L | Lost Gauge | | | 2T | Lost Gauge | | |
| 3L | 0.0132 | 0.0032 | 2,417,019 | | | | |
| 4L | 0.0115 | 0.0032 | 2,891,100 | 4T | -0.0002 | 0.0000 | 0.0574 |
| Average | | | 2,536,132 | | | | 0.0574 |

Stress-Strain Curve -40_3_(09-03), Long.



Stress-Strain Curve -40_3_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 10% and 35% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-4-N40-FY09**
 Test Date: 1/31/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 23,540 lbs
 Tensile Strength, ST_x : 91,772 psi
 Tensile Modulus, E_x : 2,898,267 psi
 Ultimate Strain, ϵ_x : 0.0317 in/in
 Poisson's Ratio, v_{xy} : 0.0634

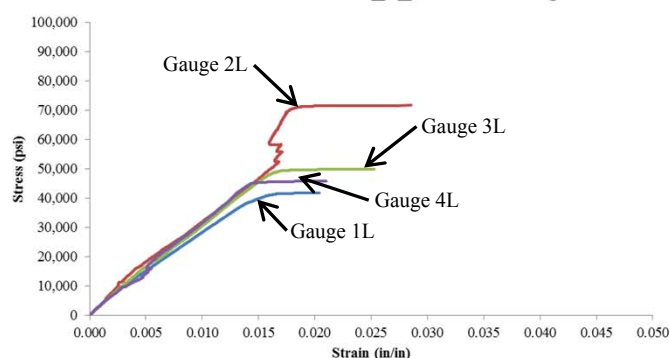
Measured Specimen Dimensions:

Width, W: 0.3643 in
 Thickness, H: 0.7041 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 10% Max Load: 2,354 lbs
 35% Max Load: 8,239 lbs

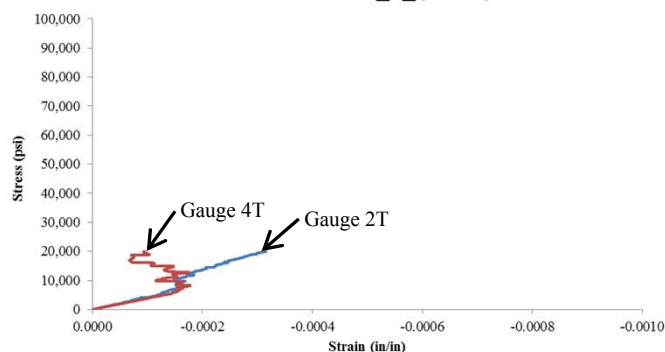
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 35% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0115 | 0.0028 | 2,647,289 | | | | |
| 2L | 0.0101 | 0.0023 | 2,966,928 | 2T | -0.0002 | 0.0000 | 0.0687 |
| 3L | 0.0106 | 0.0026 | 2,891,533 | | | | |
| 4L | 0.0102 | 0.0028 | 3,087,317 | 4T | -0.0002 | 0.0000 | 0.0582 |
| Average | | | 2,898,267 | | | | 0.0634 |

Stress-Strain Curve -40_4_(09-03), Long.



Stress-Strain Curve -40_4_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 10% and 35% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-5-N40-FY09**
 Test Date: 6/27/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

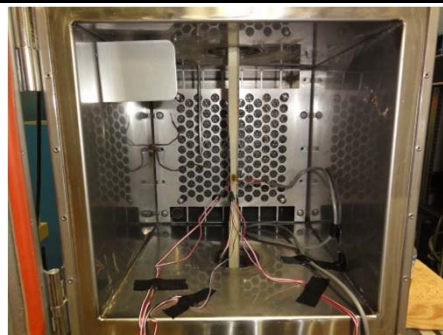
Ultimate Load, P_x : 23,180 lbs
 Tensile Strength, ST_x : 97,100 psi
 Tensile Modulus, E_x : 3,062,260 psi
 Ultimate Strain, ϵ_x : 0.0317 in/in
 Poisson's Ratio, v_{xy} : 0.0947

Measured Specimen Dimensions:

Width, W: 0.3300 in
 Thickness, H: 0.7234 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 10% Max Load: 2,318 lbs
 35% Max Load: 8,113 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

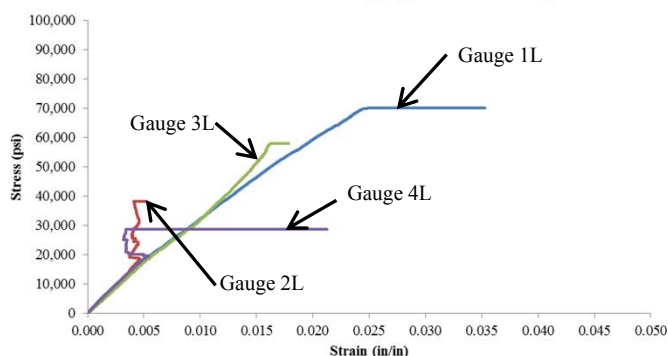


PICTURE OF SPECIMEN POST-TEST

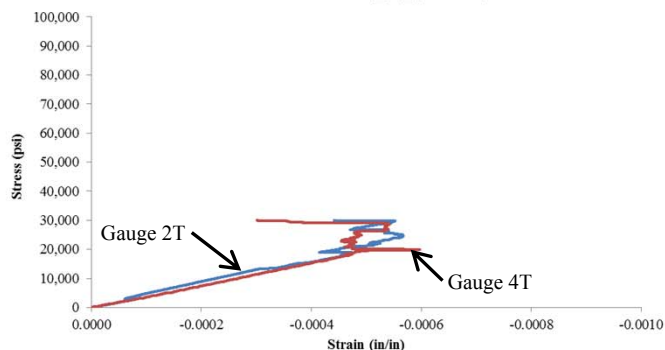


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 35% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0106 | 0.0025 | 2,974,266 | | | | |
| 2L | INVALID | 0.0026 | INVALID | 2T | -0.0002 | 0.0000 | 0.0845 |
| 3L | 0.0105 | 0.0028 | 3,150,254 | | | | |
| 4L | INVALID | 0.0025 | INVALID | 4T | -0.0003 | 0.0000 | 0.1048 |
| Average | | | 3,062,260 | | | | 0.0947 |

Stress-Strain Curve -40_5_(09-03), Long.



Stress-Strain Curve -40_5_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 10% and 35% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-TX-70-FY09

Material: 3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers

Nominal Temperature: 70°F

Properties Measured: ST_x , E_x , ν_{xy}

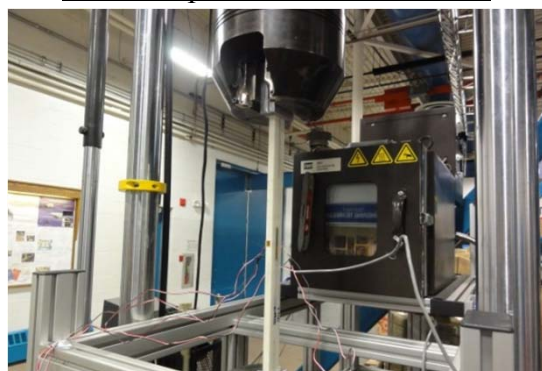
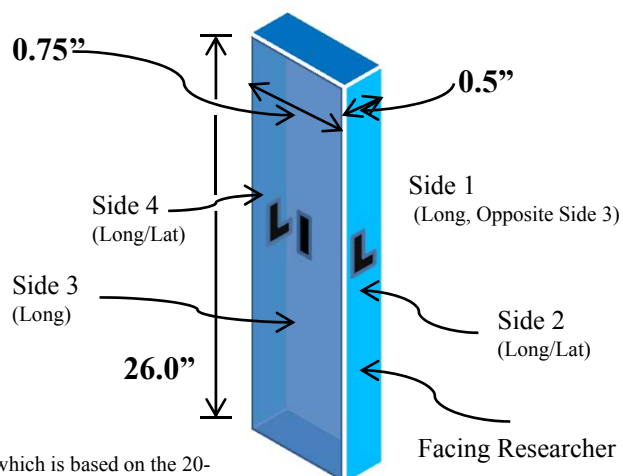
Average Material Properties (5 Specimens):

Ultimate Load, P_x : 20,005 lbs
 Tensile Strength, ST_x : 83,782 psi
 Tensile Modulus, E_x : 3,061,313 psi
 Ultimate Strain, ϵ_x : 0.0272 in/in
 Poisson's Ratio, ν_{xy} : 0.0632

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|-------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT3-TX-1-70-FY09 | 21,203 | 88,869 | 3,165,251 | 0.0281 | 0.0565 | LGM |
| 2 | MAT3-TX-2-70-FY09 | 19,839 | 84,432 | 3,280,179 | 0.0257 | 0.0636 | LGM |
| 3 | MAT3-TX-3-70-FY09 | 19,530 | 82,195 | 2,897,710 | 0.0284 | 0.0707 | LGM |
| 4 | MAT3-TX-4-70-FY09 | 19,890 | 82,138 | 2,913,838 | 0.0282 | 0.0584 | LGM |
| 5 | MAT3-TX-5-70-FY09 | 19,563 | 81,276 | 3,049,588 | 0.0267 | 0.0600 | LGM |
| Average | | 20,005 | 83,782 | 3,061,313 | 0.0272 | 0.0632 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. In this test, load is applied within this fiber plane. Aramid fibers also exist in the "z" direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint is used to eliminate all moments about the fixed lower head and allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) LGM corresponds with L=lateral, G=gauge area, M=middle of specimen
- 3) See F-8 to F-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-1-70-FY09**
 Test Date: 6/28/2012
 Specimen Received: 4/22/2012
 Properties Measured: ST_x , E_x , ν_{xy}

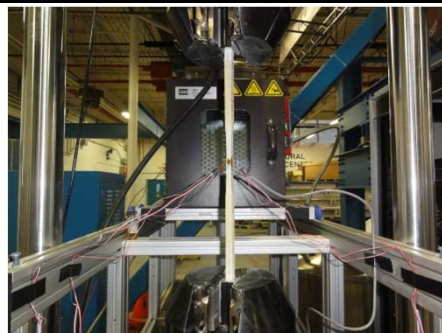
Average Material Properties:

Ultimate Load, P_x : 21,203 lbs
 Tensile Strength, ST_x : 88,869 psi
 Tensile Modulus, E_x : 3,165,251 psi
 Ultimate Strain, ϵ_x : 0.0281 in/in
 Poisson's Ratio, ν_{xy} : 0.0565

Measured Specimen Dimensions:

Width, W: 0.3300 in
 Thickness, H: 0.7230 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 4,241 lbs
 50% Max Load: 10,602 lbs

PICTURE OF SPECIMEN PRE-TEST



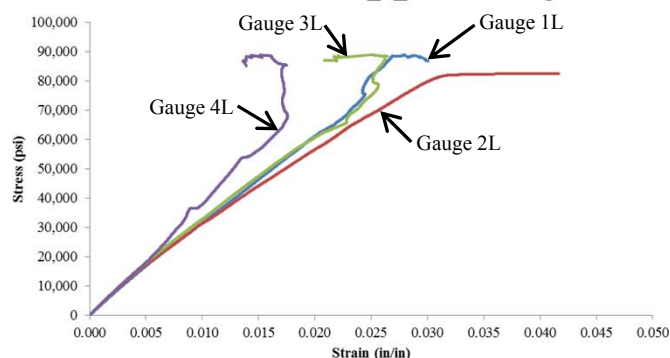
PICTURE OF SPECIMEN POST-TEST



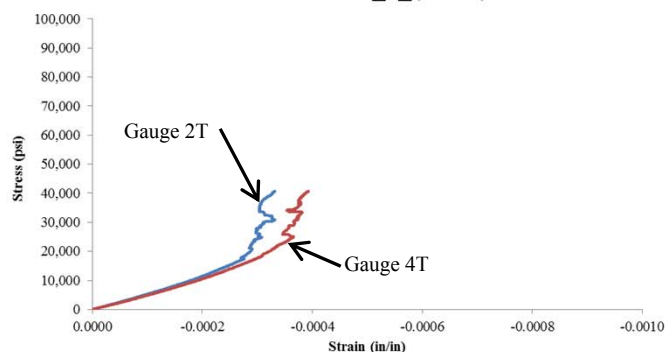
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 20% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0144 | 0.0053 | 2,934,180 | | | | |
| 2L | 0.0151 | 0.0052 | 2,697,935 | 2T | -0.0003 | 0.0000 | 0.0519 |
| 3L | 0.0139 | 0.0050 | 2,973,413 | | | | |
| 4L | 0.0115 | 0.0049 | 4,055,476 | 4T | -0.0003 | 0.0000 | 0.0611 |
| Average | | | 3,165,251 | | | | 0.0565 |

Stress-Strain Curve 70_1_(09-03), Long.



Stress-Strain Curve 70_1_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-2-70-FY09**
 Test Date: 6/28/2012
 Specimen Received: 4/22/2012
 Properties Measured: ST_x , E_x , ν_{xy}

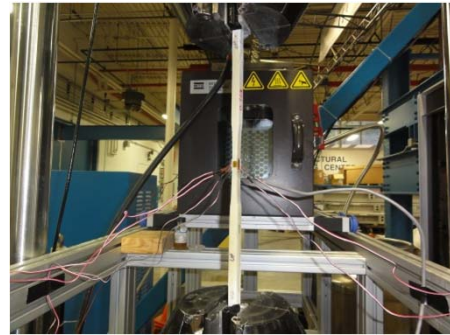
Average Material Properties:

Ultimate Load, P_x : 19,839 lbs
 Tensile Strength, ST_x : 84,432 psi
 Tensile Modulus, E_x : 3,280,179 psi
 Ultimate Strain, ϵ_x : 0.0257 in/in
 Poisson's Ratio, ν_{xy} : 0.0636

Measured Specimen Dimensions:

Width, W: 0.3250 in
 Thickness, H: 0.7230 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 3,968 lbs
 50% Max Load: 9,920 lbs

PICTURE OF SPECIMEN PRE-TEST



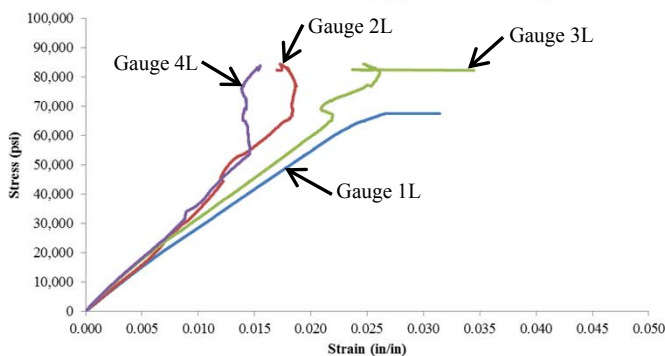
PICTURE OF SPECIMEN POST-TEST



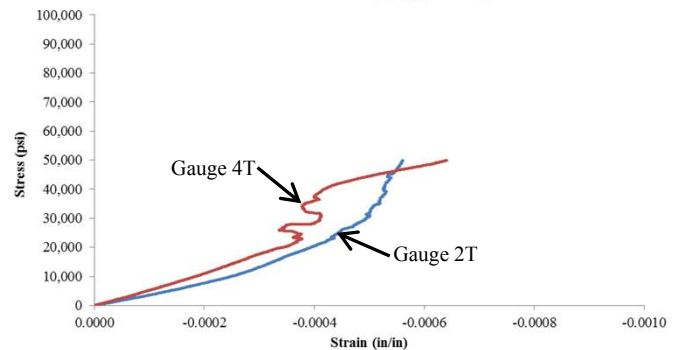
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 20% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0152 | 0.0056 | 2,641,920 | | | | |
| 2L | 0.0118 | 0.0053 | 3,926,796 | 2T | -0.0003 | 0.0000 | 0.0651 |
| 3L | 0.0138 | 0.0047 | 2,784,355 | | | | |
| 4L | 0.0113 | 0.0046 | 3,767,644 | 4T | -0.0003 | 0.0000 | 0.0620 |
| Average | | | 3,280,179 | | | | 0.0636 |

Stress-Strain Curve 70_2_(09-03), Long.



Stress-Strain Curve 70_2_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-3-70-FY09**
 Test Date: 6/28/2012
 Specimen Received: 4/22/2012
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 19,530 lbs
 Tensile Strength, ST_x : 82,195 psi
 Tensile Modulus, E_x : 2,897,710 psi
 Ultimate Strain, ϵ_x : 0.0284 in/in
 Poisson's Ratio, v_{xy} : 0.0707

Measured Specimen Dimensions:

Width, W: 0.3300 in
 Thickness, H: 0.7200 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 3,906 lbs
 50% Max Load: 9,765 lbs

PICTURE OF SPECIMEN PRE-TEST



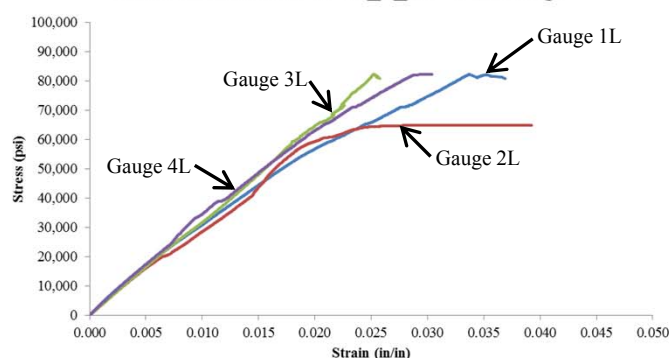
PICTURE OF SPECIMEN POST-TEST



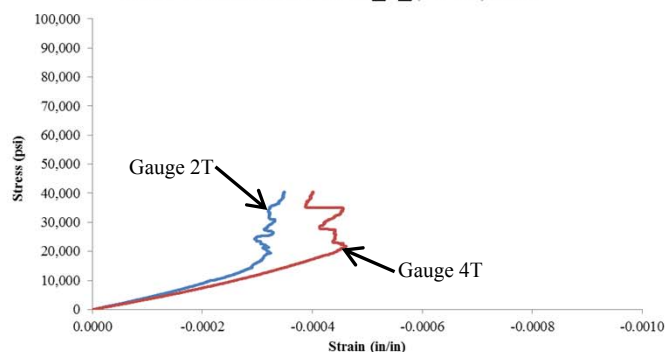
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 20% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0138 | 0.0048 | 2,741,237 | | | | |
| 2L | 0.0145 | 0.0051 | 2,618,053 | 2T | -0.0003 | 0.0000 | 0.0591 |
| 3L | 0.0129 | 0.0050 | 3,091,461 | | | | |
| 4L | 0.0126 | 0.0047 | 3,140,089 | 4T | -0.0004 | 0.0000 | 0.0823 |
| Average | | | 2,897,710 | | | | 0.0707 |

Stress-Strain Curve 70_3_(09-03), Long.



Stress-Strain Curve 70_3_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-4-70-FY09**
 Test Date: 6/28/2012
 Specimen Received: 4/22/2012
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 19,890 lbs
 Tensile Strength, ST_x : 82,138 psi
 Tensile Modulus, E_x : 2,913,838 psi
 Ultimate Strain, ϵ_x : 0.0282 in/in
 Poisson's Ratio, ν_{xy} : 0.0584

Measured Specimen Dimensions:

Width, W: 0.3340 in
 Thickness, H: 0.7250 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 3,978 lbs
 50% Max Load: 9,945 lbs

PICTURE OF SPECIMEN PRE-TEST



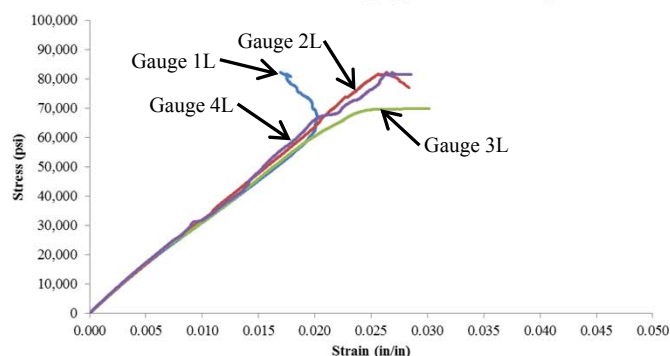
PICTURE OF SPECIMEN POST-TEST



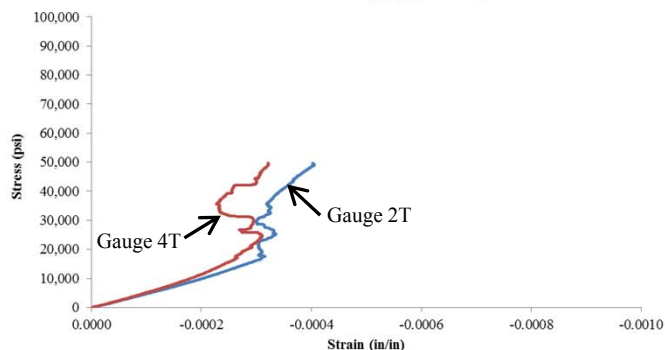
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 20% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0135 | 0.0049 | 2,848,028 | | | | |
| 2L | 0.0128 | 0.0049 | 3,095,654 | 2T | -0.0003 | 0.0000 | 0.0623 |
| 3L | 0.0134 | 0.0048 | 2,849,823 | | | | |
| 4L | 0.0133 | 0.0047 | 2,861,847 | 4T | -0.0003 | 0.0000 | 0.0545 |
| Average | | | 2,913,838 | | | | 0.0584 |

Stress-Strain Curve 70_4_(09-03), Long.



Stress-Strain Curve 70_4_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-5-70-FY09**
 Test Date: 6/29/2012
 Specimen Received: 4/22/2012
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 19,563 lbs
 Tensile Strength, ST_x : 81,276 psi
 Tensile Modulus, E_x : 3,049,588 psi
 Ultimate Strain, ϵ_x : 0.0267 in/in
 Poisson's Ratio, ν_{xy} : 0.0600

Measured Specimen Dimensions:

Width, W: 0.3320 in
 Thickness, H: 0.7250 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 3,913 lbs
 50% Max Load: 9,782 lbs

PICTURE OF SPECIMEN PRE-TEST



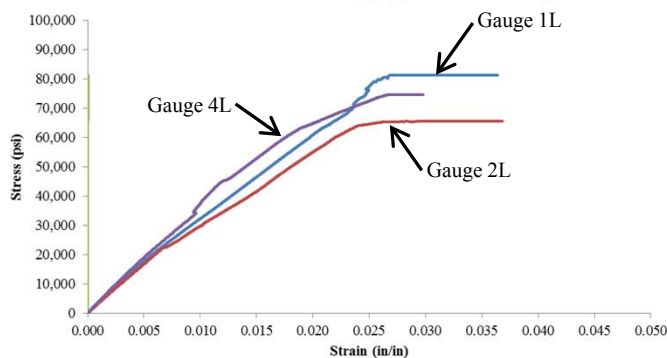
PICTURE OF SPECIMEN POST-TEST



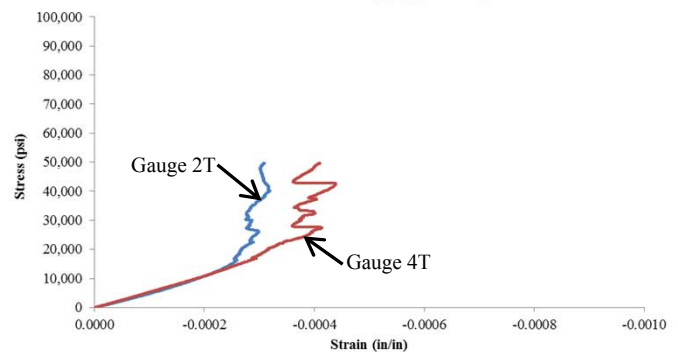
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 20% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0130 | 0.0046 | 2,900,964 | | | | |
| 2L | 0.0146 | 0.0049 | 2,496,329 | 2T | -0.0003 | 0.0000 | 0.0530 |
| 3L | Lost Gauge | | | | | | |
| 4L | 0.0107 | 0.0042 | 3,751,471 | 4T | -0.0003 | 0.0000 | 0.0669 |
| Average | | | 3,049,588 | | | | 0.0600 |

Stress-Strain Curve 70_5_(09-03), Long.



Stress-Strain Curve 70_5_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-TX-140-FY09

Material: 3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers

Nominal Temperature: 140°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 21,489 lbs
 Tensile Strength, ST_x : 76,055 psi
 Tensile Modulus, E_x : 2,939,730 psi
 Ultimate Strain, ϵ_x : 0.0260 in/in
 Poisson's Ratio, ν_{xy} : 0.0575

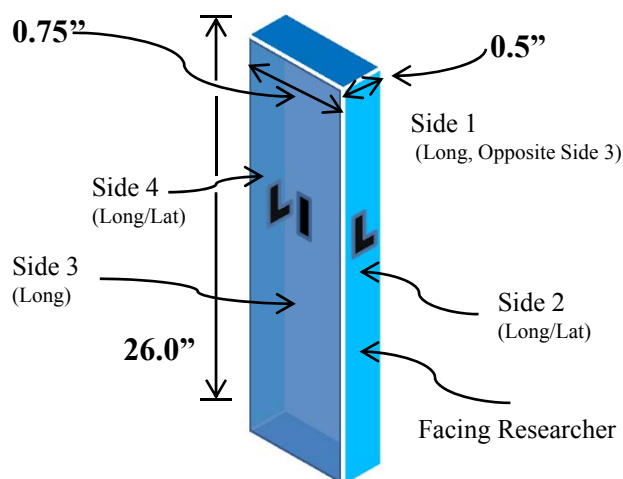
| Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT3-TX-1-140-FY09 | 19,891 | 69,819 | 2,424,562 | 0.0288 | 0.0834 | LGM |
| MAT3-TX-2-140-FY09 | 22,712 | 80,831 | 3,199,445 | 0.0253 | 0.0438 | LGM |
| MAT3-TX-3-140-FY09 | 22,052 | 77,709 | 3,027,903 | 0.0257 | 0.0613 | LGM |
| MAT3-TX-4-140-FY09 | 21,526 | 76,350 | 2,962,220 | 0.0258 | 0.0512 | LGM |
| MAT3-TX-5-140-FY09 | 21,263 | 75,568 | 3,084,523 | 0.0245 | 0.0480 | LGM |
| Average | 21,489 | 76,055 | 2,939,730 | 0.0260 | 0.0575 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and the In-Plane Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. In this test, load is applied within this fiber plane. Aramid fibers also exist in the "z" direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint is used to eliminate all moments about the fixed lower head and allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) 7 specimens tested, group of 5 displayed with relevant data shown
- 2) LGM corresponds with L=lateral, G=gauge area, M=middle of specimen
- 3) See F-14 to F-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-1-140-FY09**
 Test Date: 1/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 19,891 lbs
 Tensile Strength, ST_x : 69,819 psi
 Tensile Modulus, E_x : 2,424,562 psi
 Ultimate Strain, ϵ_x : 0.0288 in/in
 Poisson's Ratio, v_{xy} : 0.0834

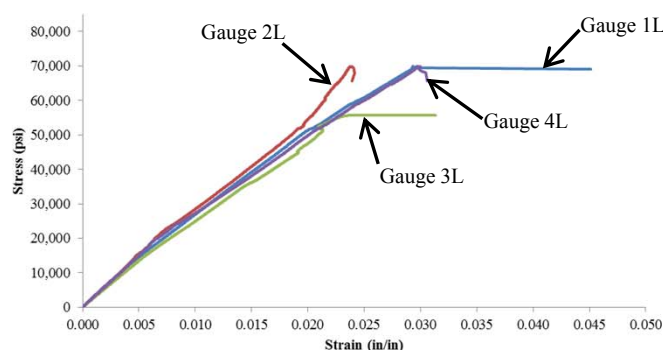
Measured Specimen Dimensions:

Width, W: 0.3668 in
 Thickness, H: 0.7767 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 3,978 lbs
 50% Max Load: 9,946 lbs

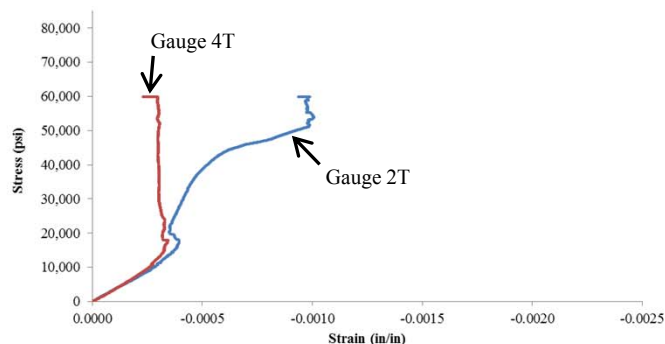
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0132 | 0.0048 | 2,478,130 | | | | |
| 2L | 0.0127 | 0.0045 | 2,566,950 | 2T | -0.0002 | 0.0000 | 0.0863 |
| 3L | 0.0143 | 0.0052 | 2,305,226 | | | | |
| 4L | 0.0135 | 0.0046 | 2,347,941 | 4T | -0.0002 | 0.0000 | 0.0804 |
| Average | | | 2,424,562 | | | | 0.0834 |

Stress-Strain Curve 140_1_(09-03), Long.



Stress-Strain Curve 140_1_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-2-140-FY09**
 Test Date: 1/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 22,712 lbs
 Tensile Strength, ST_x : 80,831 psi
 Tensile Modulus, E_x : 3,199,445 psi
 Ultimate Strain, ϵ_x : 0.0253 in/in
 Poisson's Ratio, v_{xy} : 0.0438

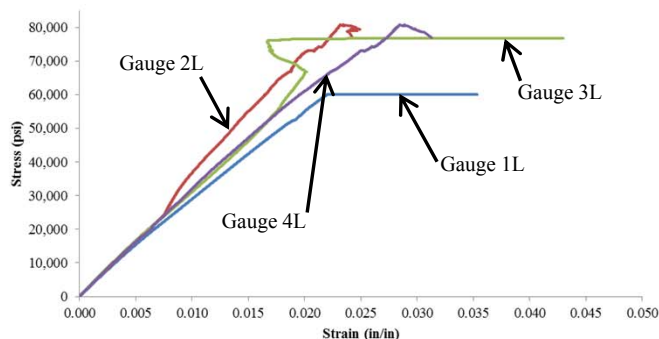
Measured Specimen Dimensions:

Width, W: 0.3620 in
 Thickness, H: 0.7762 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 4,542 lbs
 50% Max Load: 11,356 lbs

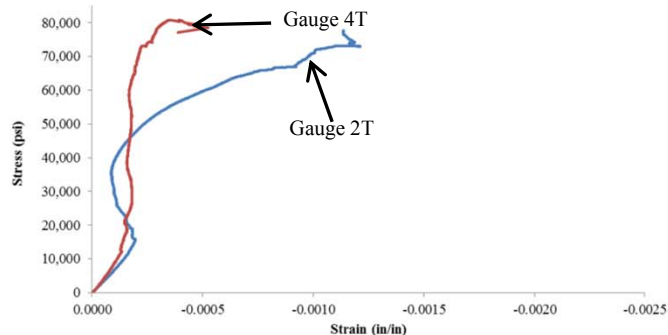
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0142 | 0.0052 | 2,696,274 | | | | |
| 2L | 0.0110 | 0.0049 | 4,035,445 | 2T | -0.0001 | 0.0000 | 0.0485 |
| 3L | 0.0131 | 0.0048 | 2,928,752 | | | | |
| 4L | 0.0127 | 0.0049 | 3,137,310 | 4T | -0.0001 | 0.0000 | 0.0392 |
| Average | | | 3,199,445 | | | | 0.0438 |

Stress-Strain Curve 140_2_(09-03), Long.



Stress-Strain Curve 140_2_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-3-140-FY09**
 Test Date: 1/18/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 22,052 lbs
 Tensile Strength, ST_x : 77,709 psi
 Tensile Modulus, E_x : 3,027,903 psi
 Ultimate Strain, ϵ_x : 0.0257 in/in
 Poisson's Ratio, v_{xy} : 0.0613

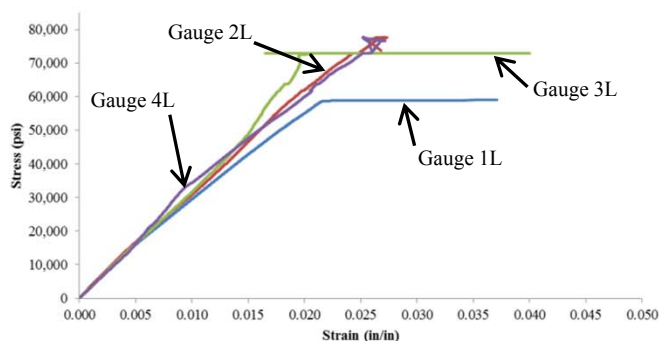
Measured Specimen Dimensions:

Width, W: 0.3609 in
 Thickness, H: 0.7863 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 4,410 lbs
 50% Max Load: 11,026 lbs

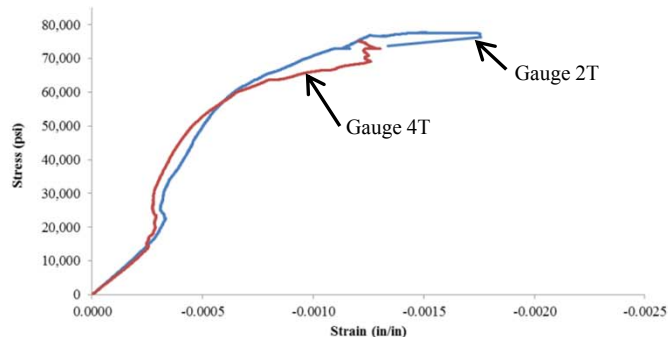
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0135 | 0.0048 | 2,696,155 | | | | |
| 2L | 0.0126 | 0.0046 | 2,898,961 | 2T | -0.0001 | 0.0000 | 0.0616 |
| 3L | 0.0122 | 0.0047 | 3,134,758 | | | | |
| 4L | 0.0117 | 0.0048 | 3,381,739 | 4T | -0.0001 | 0.0000 | 0.0611 |
| Average | | | 3,027,903 | | | | 0.0613 |

Stress-Strain Curve 140_3_(09-03), Long.



Stress-Strain Curve 140_3_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-4-140-FY09**
 Test Date: 1/31/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 21,526 lbs
 Tensile Strength, ST_x : 76,350 psi
 Tensile Modulus, E_x : 2,962,220 psi
 Ultimate Strain, ϵ_x : 0.0258 in/in
 Poisson's Ratio, v_{xy} : 0.0512

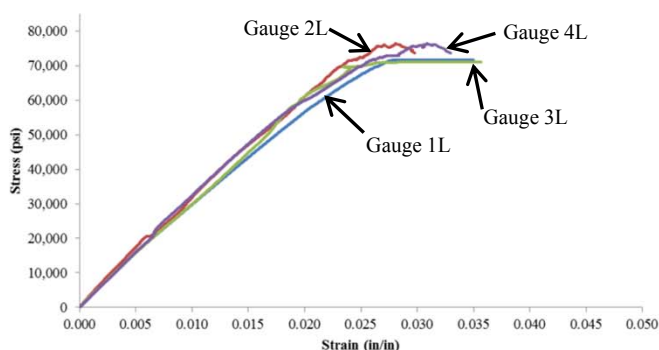
Measured Specimen Dimensions:

Width, W: 0.3609 in
 Thickness, H: 0.7812 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 4,305 lbs
 50% Max Load: 10,763 lbs

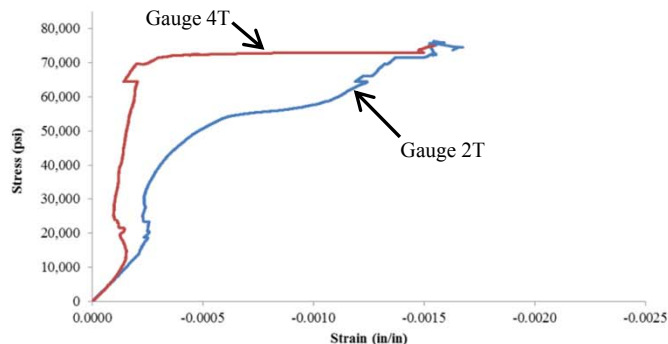
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0131 | 0.0048 | 2,763,362 | | | | |
| 2L | 0.0119 | 0.0044 | 3,020,897 | 2T | -0.0001 | 0.0000 | 0.0564 |
| 3L | 0.0128 | 0.0048 | 2,855,349 | | | | |
| 4L | 0.0119 | 0.0047 | 3,209,270 | 4T | -0.0001 | 0.0000 | 0.0460 |
| Average | | | 2,962,220 | | | | 0.0512 |

Stress-Strain Curve 140_4_(09-03), Long.



Stress-Strain Curve 140_4_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT3-TX-5-140-FY09**
 Test Date: 1/31/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 21,263 lbs
 Tensile Strength, ST_x : 75,568 psi
 Tensile Modulus, E_x : 3,084,523 psi
 Ultimate Strain, ϵ_x : 0.0245 in/in
 Poisson's Ratio, v_{xy} : 0.0480

Measured Specimen Dimensions:

Width, W : 0.3613 in
 Thickness, H : 0.7788 in
 Laboratory Temperature: 68°F
 Failure Mode: LGM
 20% Max Load: 4,253 lbs
 50% Max Load: 10,632 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

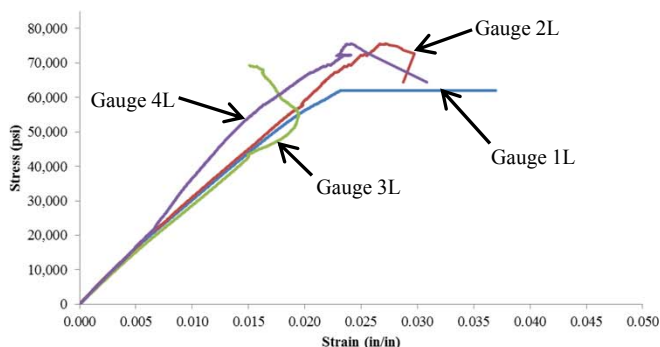


PICTURE OF SPECIMEN POST-TEST

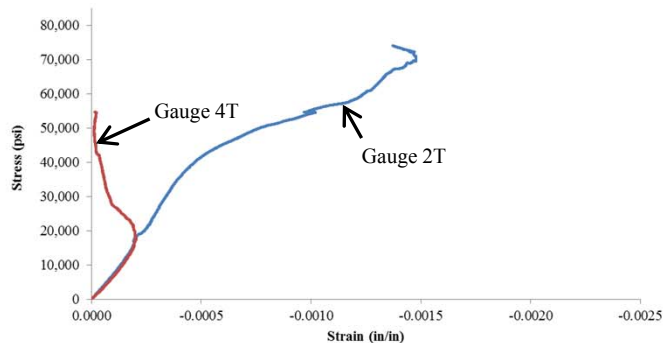


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 10% Max Load (in/in) | Strain @ 0% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0127 | 0.0046 | 2,785,104 | | | | |
| 2L | 0.0124 | 0.0046 | 2,917,263 | 2T | -0.0001 | 0.0000 | 0.0464 |
| 3L | 0.0133 | 0.0050 | 2,713,645 | | | | |
| 4L | 0.0104 | 0.0046 | 3,922,078 | 4T | -0.0001 | 0.0000 | 0.0496 |
| Average | | | 3,084,523 | | | | 0.0480 |

Stress-Strain Curve 140_5_(09-03), Long.



Stress-Strain Curve 140_5_(09-03), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *The tensile modulus was calculated using strain at 20% and 50% of max load
- *The Poisson's Ratio was calculated using strain at 0% and 10% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-CX-N40-FY09
 Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber
 Nominal Temperature: -40°F
 Properties Measured: SC_x , E_x , ν_{xy}
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x : 45,057 lbs
 Compressive Strength, SC_x : 68,346 psi
 Compressive Modulus, E_x : 3,786,027 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson's Ratio, ν_{xy} : 0.061

| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT3-CX-01-N40-FY09 | 50,440 | 72,109 | 4,079,460 | 0.018 | 0.063 | Delamination |
| MAT3-CX-02-N40-FY09 | 43,091 | 67,690 | 3,773,829 | 0.018 | 0.067 | Delamination |
| MAT3-CX-03-N40-FY09 | 40,267 | 64,592 | 3,633,732 | 0.018 | 0.053 | Delamination |
| MAT3-CX-04-N40-FY09 | 45,094 | 68,521 | 3,729,020 | 0.018 | 0.062 | Delamination |
| MAT3-CX-05-N40-FY09 | 46,392 | 68,820 | 3,714,092 | 0.019 | I.D. | Delamination |
| Average | 45,057 | 68,346 | 3,786,027 | 0.018 | 0.061 | |

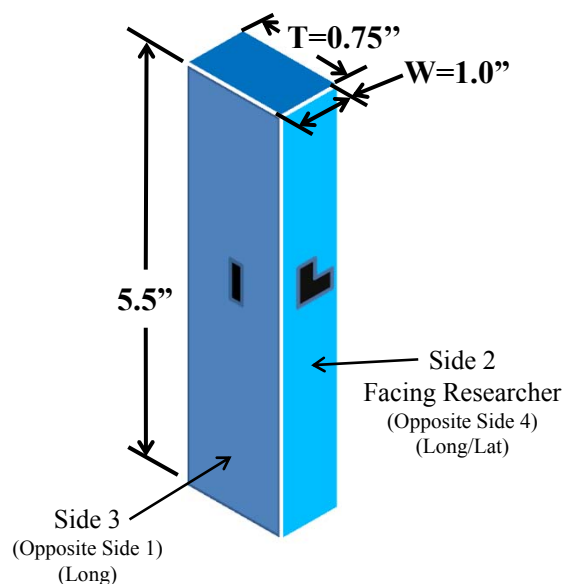
Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

Compressive properties are measured along the 'x' and 'y' directions which are assumed equal. This material consists of S2-glass fibers along the 'x' and 'y' plane and aramid fibers along the 'z' axis.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See F-20 to F-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-01-N40-FY09**
 Test Date: 10/7/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 50,440 lbs
 Compressive Strength, SC_x : 72,109 psi
 Compressive Modulus, E_x : 4,079,460 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson's Ratio, v_{xy} : 0.063

Measured Specimen Dimensions:

Width, W: 0.9436 in
 Thickness, H: 0.7413 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 10,088 lbs
 50% Max Load: 25,220 lbs

PICTURE OF SPECIMEN PRE-TEST



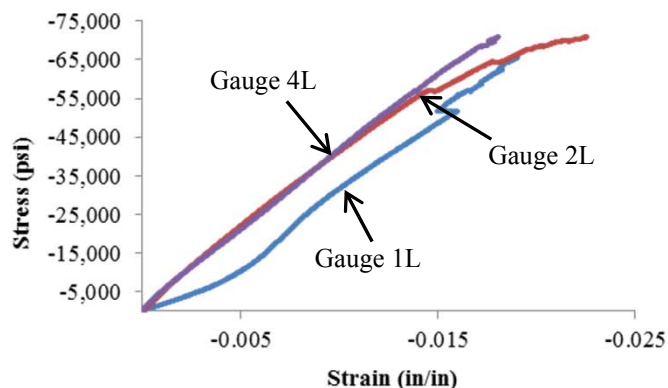
PICTURE OF SPECIMEN POST-TEST



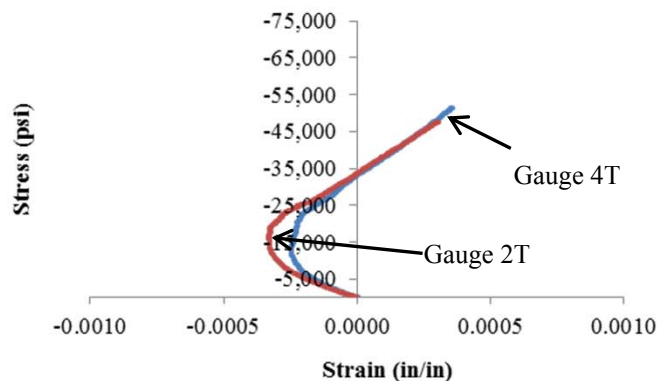
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.01122 | -0.00609 | 4,219,988 | | | | |
| 2L | -0.00855 | -0.00312 | 3,982,878 | 2T | 0.00006 | -0.00024 | 0.055 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.00859 | -0.00323 | 4,035,515 | 4T | 0.00005 | -0.00033 | 0.070 |
| Average | | | 4,079,460 | | | | 0.063 |

Stress-Strain Curve N40_01_(09-03)_Long



Stress-Strain Curve N40_01_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder(calibrated 6-3-10)
- *Strain gauge three was lost.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-02-N40-FY09**
 Test Date: 10/11/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 43,091 lbs
 Compressive Strength, SC_x : 67,690 psi
 Compressive Modulus, E_x : 3,773,829 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson's Ratio, ν_{xy} : 0.067

Measured Specimen Dimensions:

Width, W: 0.9649 in
 Thickness, H: 0.6598 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 8,618 lbs
 50% Max Load: 21,546 lbs

PICTURE OF SPECIMEN PRE-TEST



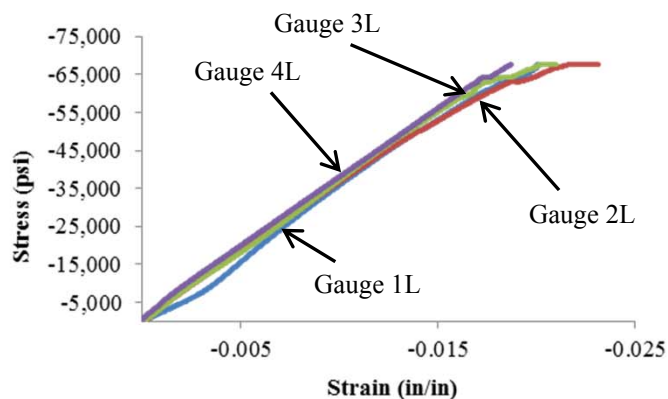
PICTURE OF SPECIMEN POST-TEST



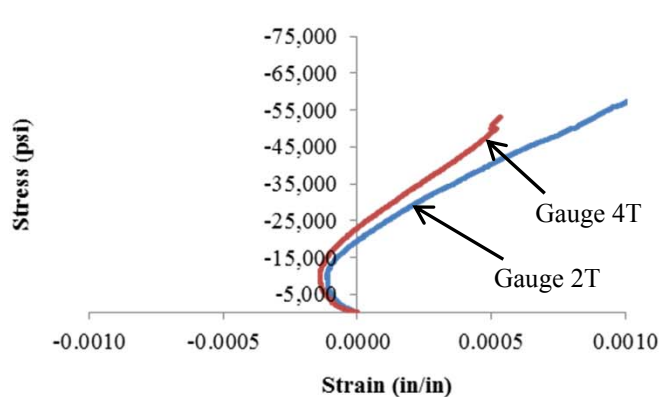
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00944 | -0.00452 | 4,128,144 | | | | |
| 2L | -0.00919 | -0.00359 | 3,627,195 | 2T | 0.00033 | -0.00009 | 0.075 |
| 3L | -0.00912 | -0.00365 | 3,713,958 | | | | |
| 4L | -0.00880 | -0.00320 | 3,626,018 | 4T | 0.00021 | -0.00012 | 0.060 |
| Average | | | 3,773,829 | | | | 0.067 |

Stress-Strain Curve N40_02_(09-03)_Long



Stress-Strain Curve N40_02_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-03-N40-FY09**
 Test Date: 10/12/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 40,267 lbs
 Compressive Strength, SC_x : 64,592 psi
 Compressive Modulus, E_x : 3,633,732 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson's Ratio, ν_{xy} : 0.018

Measured Specimen Dimensions:

Width, W: 0.9329 in
 Thickness, H: 0.6682 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 8,053 lbs
 50% Max Load: 20,133 lbs

PICTURE OF SPECIMEN PRE-TEST



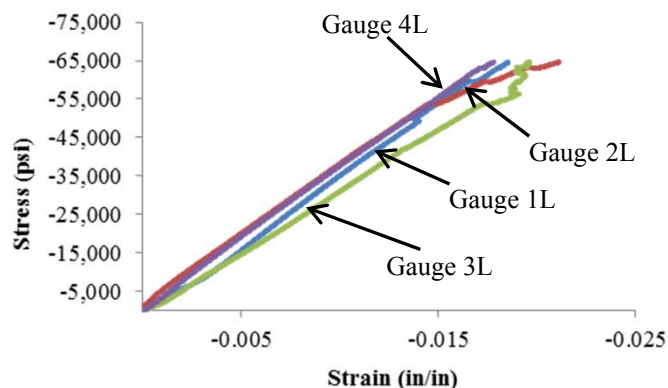
PICTURE OF SPECIMEN POST-TEST



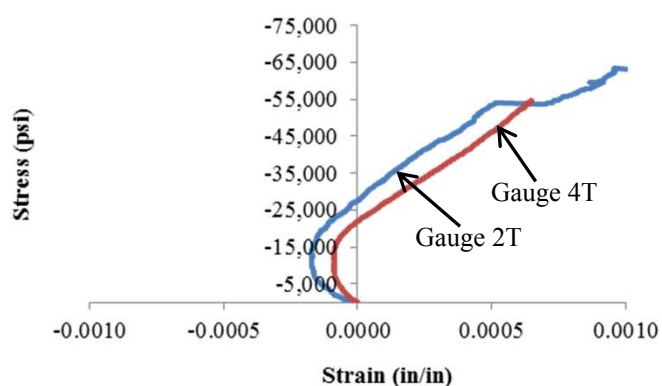
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00925 | -0.00430 | 3,914,660 | | | | |
| 2L | -0.00837 | -0.00302 | 3,616,084 | 2T | 0.00008 | -0.00017 | 0.047 |
| 3L | -0.01038 | -0.00444 | 3,261,219 | | | | |
| 4L | -0.00852 | -0.00334 | 3,742,964 | 4T | 0.00022 | -0.00009 | 0.059 |
| Average | | | 3,633,732 | | | | 0.053 |

Stress-Strain Curve N40_03_(09-03)_Long



Stress-Strain Curve N40_03_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-04-N40-FY09**
 Test Date: 11/29/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 45,094 lbs
 Compressive Strength, SC_x : 68,521 psi
 Compressive Modulus, E_x : 3,729,020 psi
 Ultimate Strain, ϵ_x : 0.018 in/in
 Poisson's Ratio, ν_{xy} : 0.062

Measured Specimen Dimensions:

Width, W: 0.9778 in
 Thickness, H: 0.6730 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 9,019 lbs
 50% Max Load: 22,547 lbs

PICTURE OF SPECIMEN PRE-TEST



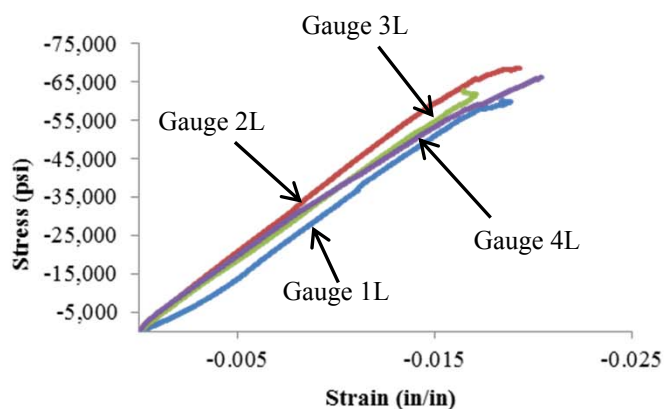
PICTURE OF SPECIMEN POST-TEST



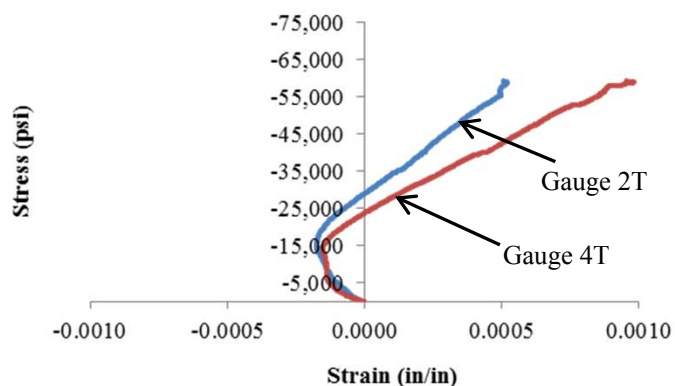
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.01043 | -0.00502 | 3,798,675 | | | | |
| 2L | -0.00843 | -0.00322 | 3,945,695 | 2T | 0.00010 | -0.00017 | 0.051 |
| 3L | -0.00927 | -0.00358 | 3,614,261 | | | | |
| 4L | -0.00912 | -0.00335 | 3,557,451 | 4T | 0.00027 | -0.00015 | 0.073 |
| Average | | | 3,729,020 | | | | 0.062 |

Stress-Strain Curve N40_04_(09-03)_Long



Stress-Strain Curve N40_04_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-05-N40-FY09**
 Test Date: 11/30/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 46,392 lbs
 Compressive Strength, SC_x : 68,820 psi
 Compressive Modulus, E_x : 3,714,092 psi
 Ultimate Strain, ϵ_x : 0.019 in/in
 Poisson's Ratio, ν_{xy} : 0.029

Measured Specimen Dimensions:

Width, W: 0.9601 in
 Thickness, H: 0.7021 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 9,278 lbs
 50% Max Load: 23,196 lbs

PICTURE OF SPECIMEN PRE-TEST



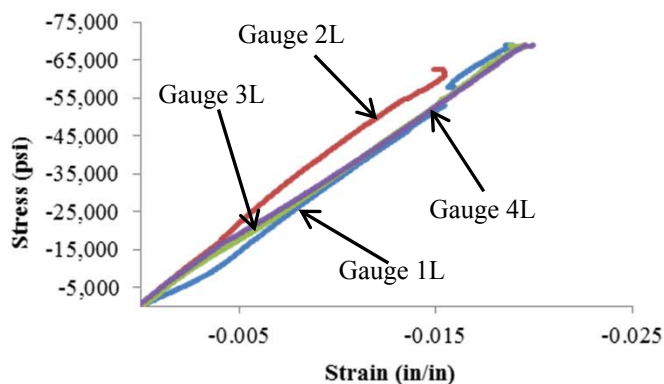
PICTURE OF SPECIMEN POST-TEST



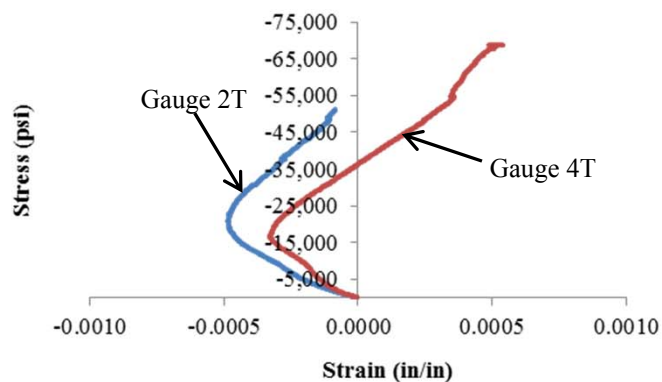
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.01023 | -0.00486 | 3,847,560 | | | | |
| 2L | -0.00787 | -0.00320 | 4,419,009 | 2T | -0.00032 | -0.00041 | 0.019 |
| 3L | -0.00989 | -0.00378 | 3,374,611 | | | | |
| 4L | -0.00979 | -0.00337 | 3,215,189 | 4T | -0.00004 | -0.00029 | 0.039 |
| Average | | | 3,714,092 | | | | I.D. |

Stress-Strain Curve N40_05_(09-03)_Lat



Stress-Strain Curve N40_05_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *A Poisson of I.D. indicates insufficient data

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

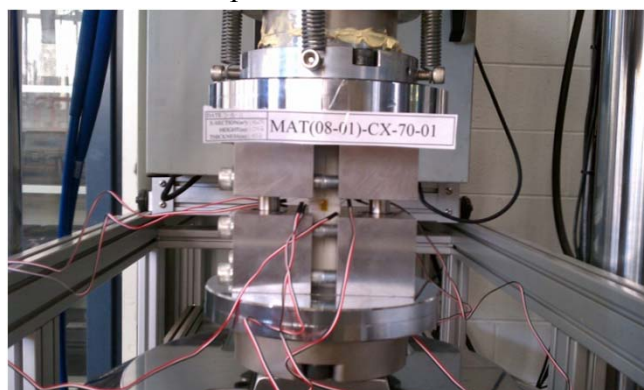
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-CX-70-FY09**
 Material: **3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_x, E_x, ν_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **34,936** **lbs**
 Compressive Strength, SC_x: **45,645** **psi**
 Compressive Modulus, E_x: **3,463,579** **psi**
 Ultimate Strain, ε_x: **0.013** **in/in**
 Poisson's Ratio, ν_{xy}: **0.076**

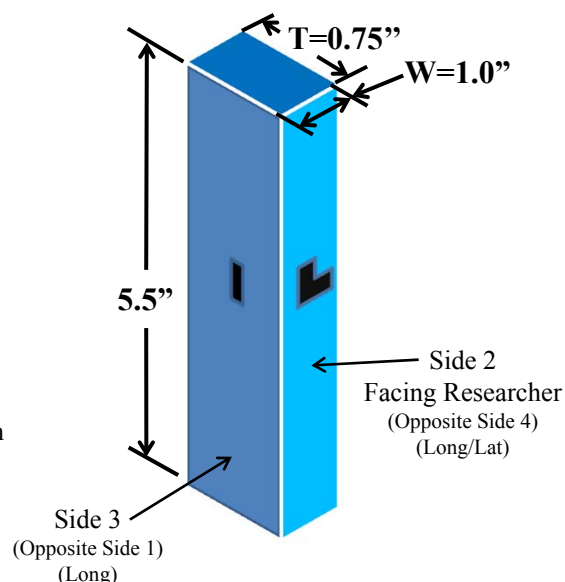
| Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|--------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| MAT3-CX-01-70-FY09 | 36,645 | 48,730 | 3,456,994 | 0.014 | 0.067 | Delamination |
| MAT3-CX-02-70-FY09 | 35,987 | 45,159 | 3,542,712 | 0.013 | 0.045 | Delamination |
| MAT3-CX-03-70-FY09 | 32,690 | 42,637 | 3,373,101 | 0.013 | 0.077 | Delamination |
| MAT3-CX-04-70-FY09 | 36,947 | 47,368 | 3,421,575 | 0.014 | 0.105 | Delamination |
| MAT3-CX-05-70-FY09 | 32,409 | 44,329 | 3,523,513 | 0.013 | 0.086 | Delamination |
| Average | 34,936 | 45,645 | 3,463,579 | 0.013 | 0.076 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width. Compressive properties are measured along the 'x' and 'y' directions which are assumed equal. This material consists of S2-glass fibers along the 'x' and 'y' plane and aramid fibers along the 'z' axis.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See F-26 to F-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-01-70-FY09**
 Test Date: 9/19/2011
 Specimen Received: 8/21/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 36,645 lbs
 Compressive Strength, SC_x : 48,730 psi
 Compressive Modulus, E_x : 3,456,994 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, v_{xy} : 0.067

Measured Specimen Dimensions:

Width, W: 0.9830 in
 Thickness, H: 0.7650 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,329 lbs
 50% Max Load: 18,322 lbs

PICTURE OF SPECIMEN PRE-TEST



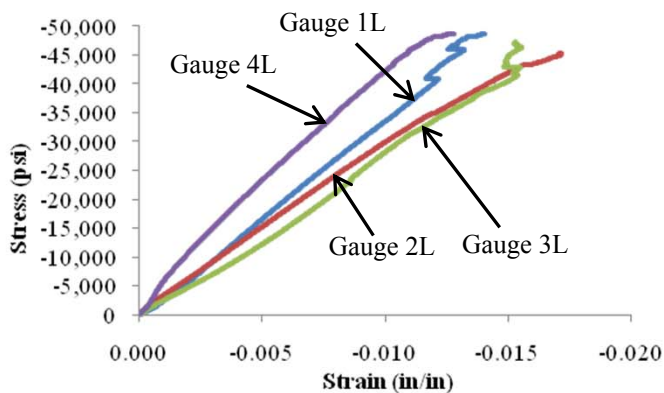
PICTURE OF SPECIMEN POST-TEST



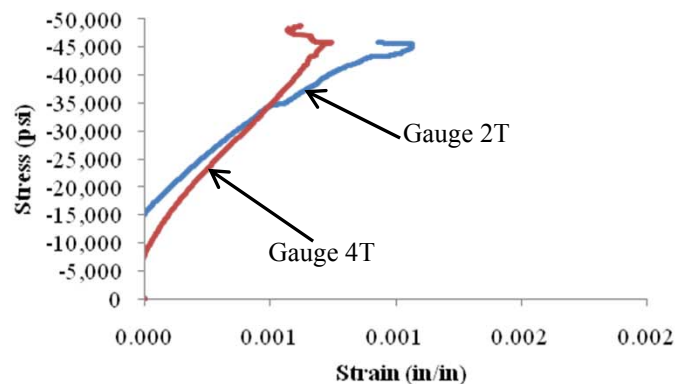
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00722 | -0.00311 | 3,559,367 | | | | |
| 2L | -0.00805 | -0.00316 | 2,992,834 | 2T | 0.00021 | -0.00009 | 0.061 |
| 3L | -0.00884 | -0.00406 | 3,062,302 | | | | |
| 4L | -0.00525 | -0.00178 | 4,213,471 | 4T | 0.00027 | 0.00002 | 0.073 |
| Average | | | 3,456,994 | | | | 0.067 |

Stress-Strain Curve 70F_01_(09-03)_Long



Stress-Strain Curve 70F_01_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-02-70-FY09**
 Test Date: 9/20/2011
 Specimen Received: 8/21/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 35,987 lbs
 Compressive Strength, SC_x : 45,159 psi
 Compressive Modulus, E_x : 3,542,712 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, v_{xy} : 0.045

Measured Specimen Dimensions:

Width, W: 1.023 in
 Thickness, H: 0.7790 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,197 lbs
 50% Max Load: 17,994 lbs

PICTURE OF SPECIMEN PRE-TEST



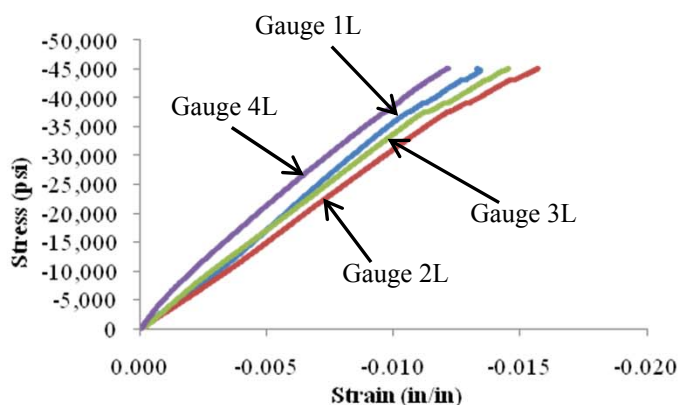
PICTURE OF SPECIMEN POST-TEST



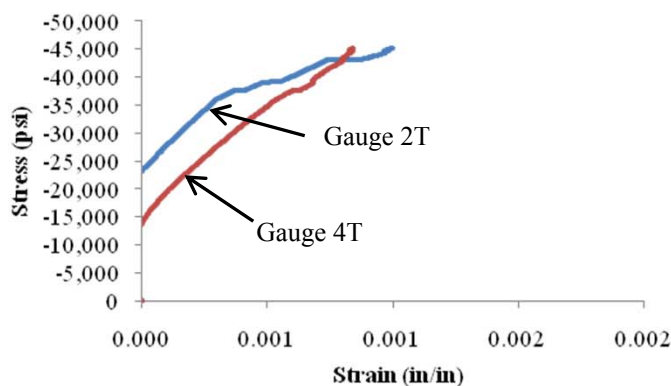
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00638 | -0.00280 | 3,789,670 | | | | |
| 2L | -0.00731 | -0.00311 | 3,231,400 | 2T | -0.00002 | -0.00013 | 0.028 |
| 3L | -0.00664 | -0.00252 | 3,285,494 | | | | |
| 4L | -0.00531 | -0.00181 | 3,864,285 | 4T | 0.00017 | -0.00005 | 0.063 |
| Average | | | 3,542,712 | | | | 0.045 |

Stress-Strain Curve 70F_02_(09-03)_Long



Stress-Strain Curve 70F_02_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-03-70-FY09**
 Test Date: 9/20/2011
 Specimen Received: 8/21/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 32,690 lbs
 Compressive Strength, SC_x : 42,637 psi
 Compressive Modulus, E_x : 3,373,101 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.077

Measured Specimen Dimensions:

Width, W: 1.0015 in
 Thickness, H: 0.7656 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,538 lbs
 50% Max Load: 16,345 lbs

PICTURE OF SPECIMEN PRE-TEST



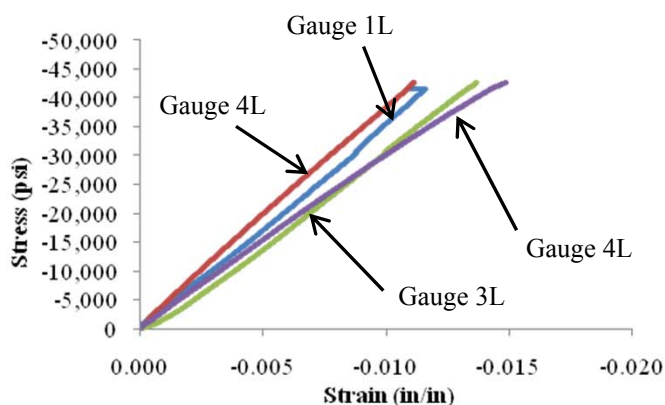
PICTURE OF SPECIMEN POST-TEST



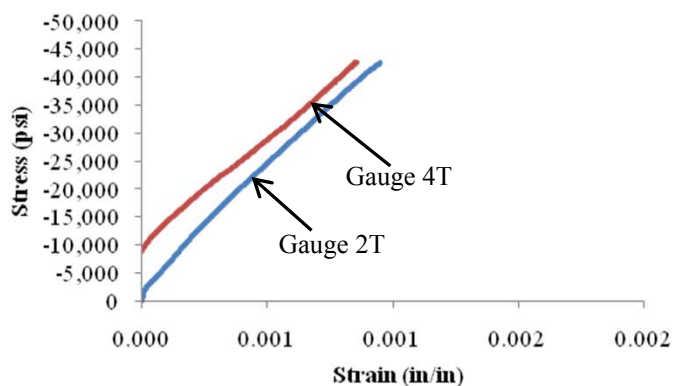
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00621 | -0.00240 | 3,359,507 | | | | |
| 2L | -0.00536 | -0.00203 | 3,843,628 | 2T | 0.00042 | 0.00014 | 0.084 |
| 3L | -0.00728 | -0.00334 | 3,244,943 | | | | |
| 4L | -0.00693 | -0.00273 | 3,044,326 | 4T | 0.00028 | -0.00001 | 0.070 |
| Average | | | 3,373,101 | | | | 0.077 |

Stress-Strain Curve 70F_03_(09-03)_Long



Stress-Strain Curve 70F_03_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-04-70-FY09**
 Test Date: 9/20/2011
 Specimen Received: 8/21/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 36,947 lbs
 Compressive Strength, SC_x : 47,368 psi
 Compressive Modulus, E_x : 3,421,575 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, v_{xy} : 0.105

Measured Specimen Dimensions:

Width, W: 1.0174 in
 Thickness, H: 0.7667 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,389 lbs
 50% Max Load: 17,474 lbs

PICTURE OF SPECIMEN PRE-TEST



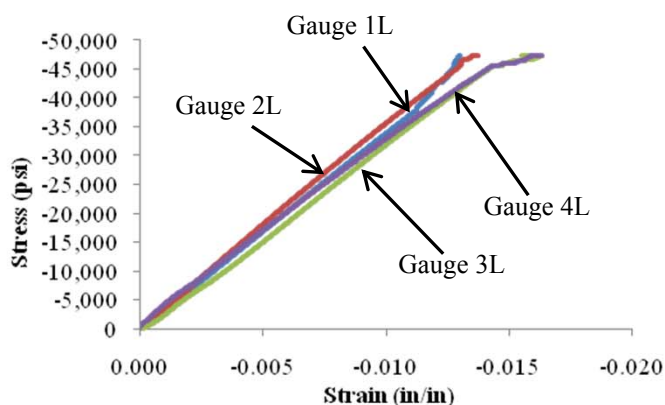
PICTURE OF SPECIMEN POST-TEST



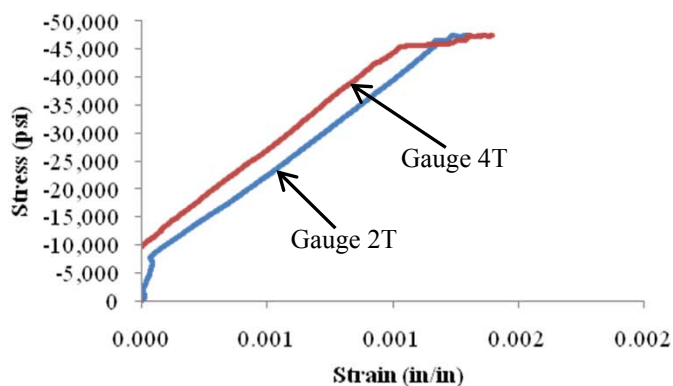
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00696 | -0.00284 | 3,450,768 | | | | |
| 2L | -0.00654 | -0.00263 | 3,626,746 | 2T | 0.00054 | 0.00008 | 0.118 |
| 3L | -0.00753 | -0.00329 | 3,356,024 | | | | |
| 4L | -0.00702 | -0.00266 | 3,252,762 | 4T | 0.00040 | -0.00001 | 0.093 |
| Average | | | 3,421,575 | | | | 0.105 |

Stress-Strain Curve 70F_04_(09-03)_Long



Stress-Strain Curve 70F_04_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-05-70-FY09**
 Test Date: 9/20/2011
 Specimen Received: 8/21/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 32,409 lbs
 Compressive Strength, SC_x : 44,329 psi
 Compressive Modulus, E_x : 3,523,513 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.086

Measured Specimen Dimensions:

Width, W : 0.9593 in
 Thickness, H : 0.7621 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,482 lbs
 50% Max Load: 16,205 lbs

PICTURE OF SPECIMEN PRE-TEST



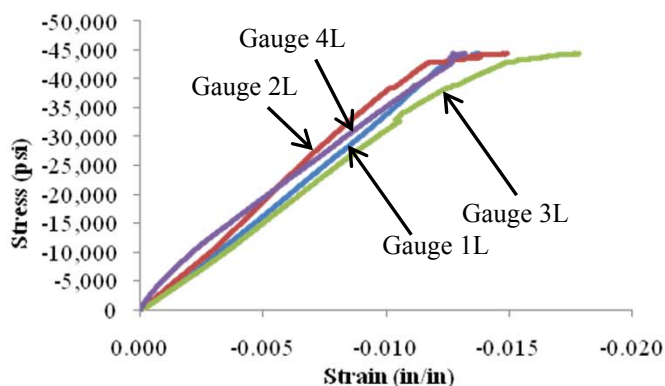
PICTURE OF SPECIMEN POST-TEST



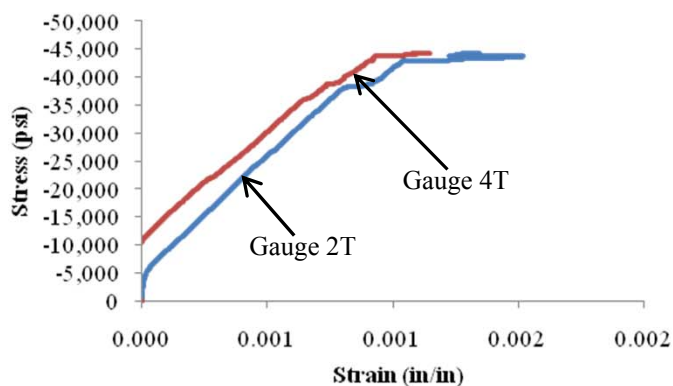
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00669 | -0.00286 | 3,471,331 | | | | |
| 2L | -0.00581 | -0.00253 | 4,058,224 | 2T | 0.00041 | 0.00009 | 0.095 |
| 3L | -0.00715 | -0.00310 | 3,287,398 | | | | |
| 4L | -0.00588 | -0.00588 | 3,277,098 | 4T | 0.00028 | -0.00003 | 0.077 |
| Average | | | 3,523,513 | | | | 0.086 |

Stress-Strain Curve 70F_05_(09-03)_Long



Stress-Strain Curve 70F_05_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-CX-140-FY09**
 Material: **3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber**
 Nominal Temperature: **140°F**
 Properties Measured: **SC_x, E_x, ν_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **22,455** **lbs**
 Compressive Strength, SC_x: **34,665** **psi**
 Compressive Modulus, E_x: **3,463,828** **psi**
 Ultimate Strain, ε_x: **0.010** **in/in**
 Poisson's Ratio, ν_{xy}: **UD**

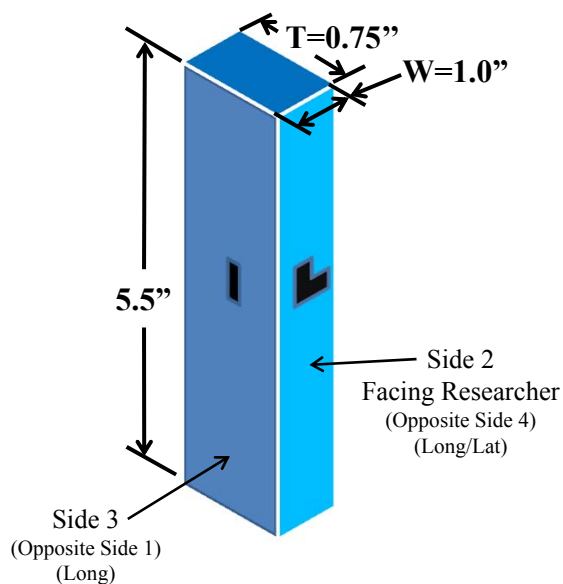
| Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|---------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| MAT3-CX-01-140-FY09 | 24,351 | 37,154 | 3,415,335 | 0.011 | ID | Delamination |
| MAT3-CX-02-140-FY09 | 19,986 | 34,692 | 3,503,191 | 0.010 | ID | Delamination |
| MAT3 CX-03-140-FY09 | 23,751 | 34,995 | 3,471,724 | 0.010 | ID | Delamination |
| MAT3-CX-04-140-FY09 | 23,078 | 33,200 | 3,651,046 | 0.009 | ID | Delamination |
| MAT3-CX-05-140-FY09 | 21,111 | 33,283 | 3,277,845 | 0.010 | ID | Delamination |
| Average | 22,455 | 34,665 | 3,463,828 | 0.010 | ID | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width. Compressive properties are measured along the 'x' and 'y' directions which are assumed equal. This material consists of S2-glass fibers along the 'x' and 'y' plane and aramid fibers along the 'z' axis. The research team was not able to identify a Poisson's ratio with how this material deforms under compression and elevated temperatures. Therefore, 'ID' represents insufficient data.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See F-32 to F-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.
- 4) A reported Poisson's Ratio of "UD" indicates un-characteristic data

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-01-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 24,351 lbs
 Compressive Strength, SC_x : 37,154 psi
 Compressive Modulus, E_x : 3,415,335 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, v_{xy} : UD

Measured Specimen Dimensions:

Width, W: 1.0311 in
 Thickness, H: 0.7880 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,870 lbs
 50% Max Load: 12,175 lbs

PICTURE OF SPECIMEN PRE-TEST



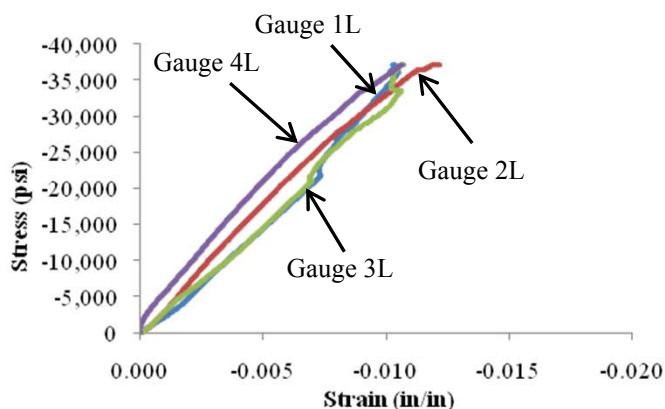
PICTURE OF SPECIMEN POST-TEST



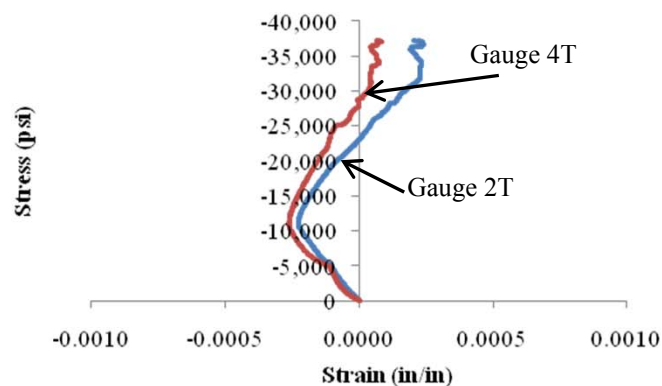
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00634 | -0.00272 | 3,081,899 | | | | |
| 2L | -0.00520 | -0.00211 | 3,615,829 | 2T | -0.00012 | -0.00017 | ID |
| 3L | -0.00623 | -0.00260 | 3,072,640 | | | | |
| 4L | -0.00432 | -0.00146 | 3,890,971 | 4T | -0.00018 | -0.00021 | ID |
| Average | | | 3,415,335 | | | | ID |

Stress-Strain Curve 140F_01_(09-03)_Long



Stress-Strain Curve 140F_01_(-09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *ID represents insufficient data.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-02-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 19,986 lbs
 Compressive Strength, SC_x : 34,692 psi
 Compressive Modulus, E_x : 3,503,191 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : UD

Measured Specimen Dimensions:

Width, W: 0.9802 in
 Thickness, H: 0.7939 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,997 lbs
 50% Max Load: 9,993 lbs

PICTURE OF SPECIMEN PRE-TEST



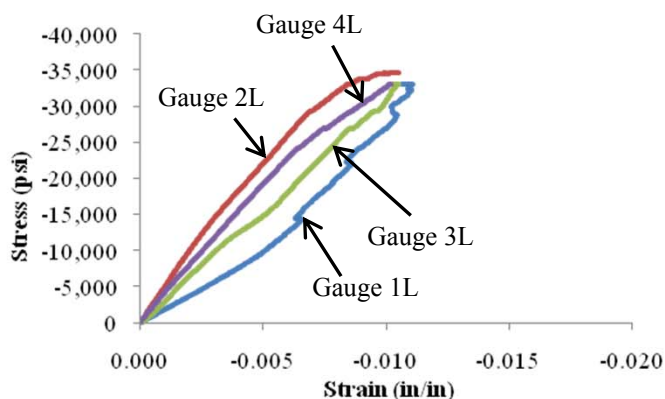
PICTURE OF SPECIMEN POST-TEST



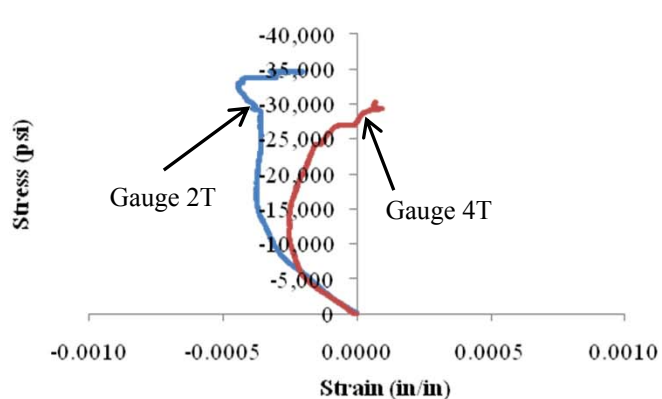
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00713 | -0.00365 | 2,995,014 | | | | |
| 2L | -0.00373 | -0.00136 | 4,403,891 | 2T | -0.00038 | -0.00024 | UD |
| 3L | -0.00580 | -0.00213 | 2,841,995 | | | | |
| 4L | -0.00447 | -0.00171 | 3,771,865 | 4T | -0.00023 | -0.00022 | UD |
| Average | | | 3,503,191 | | | | UD |

Stress-Strain Curve 140F_02_(09-03)_Long



Stress-Strain Curve 140F_02_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *ID represents insufficient data.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-03-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 23,751 lbs
 Compressive Strength, SC_x : 34,995 psi
 Compressive Modulus, E_x : 3,471,724 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : UD

Measured Specimen Dimensions:

Width, W: 0.9713 in
 Thickness, H: 0.7920 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,750 lbs
 50% Max Load: 11,876 lbs

PICTURE OF SPECIMEN PRE-TEST



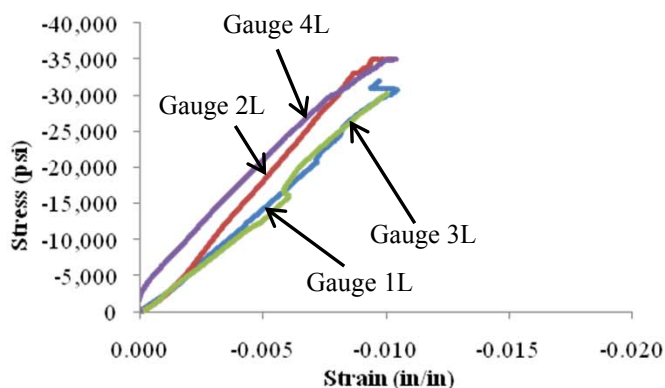
PICTURE OF SPECIMEN POST-TEST



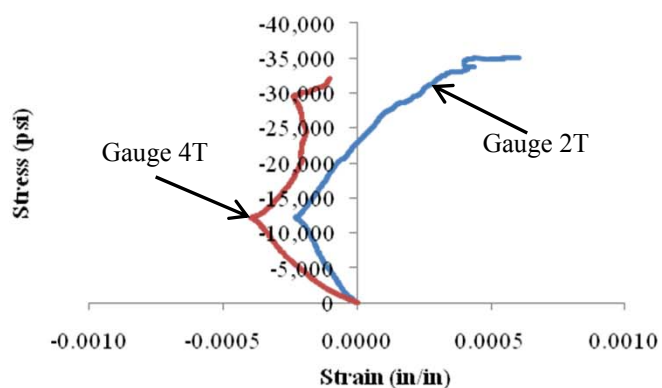
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00610 | -0.00252 | 2,929,303 | | | | |
| 2L | -0.00484 | -0.00227 | 4,078,698 | 2T | -0.00012 | -0.00014 | UD |
| 3L | -0.00594 | -0.00272 | 3,268,956 | | | | |
| 4L | -0.00396 | -0.00105 | 3,609,941 | 4T | -0.00024 | -0.00024 | UD |
| Average | | | 3,471,724 | | | | UD |

Stress-Strain Curve 140F_03_(09-03)_Long



Stress-Strain Curve 140F_03_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *ID represents insufficient data.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-04-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 23,078 lbs
 Compressive Strength, SC_x : 33,200 psi
 Compressive Modulus, E_x : 3,651,046 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : UD

Measured Specimen Dimensions:

Width, W: 0.9875 in
 Thickness, H: 0.7948 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,616 lbs
 50% Max Load: 11,539 lbs

PICTURE OF SPECIMEN PRE-TEST



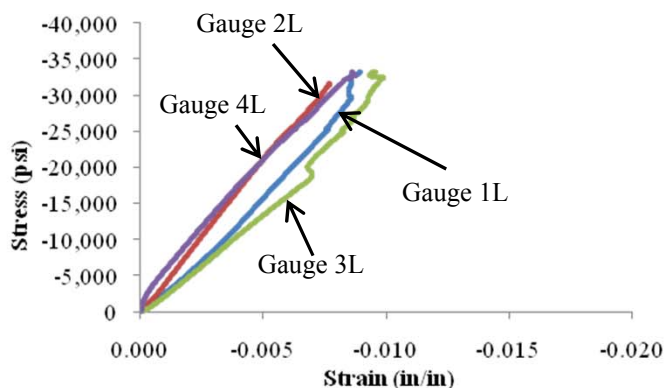
PICTURE OF SPECIMEN POST-TEST



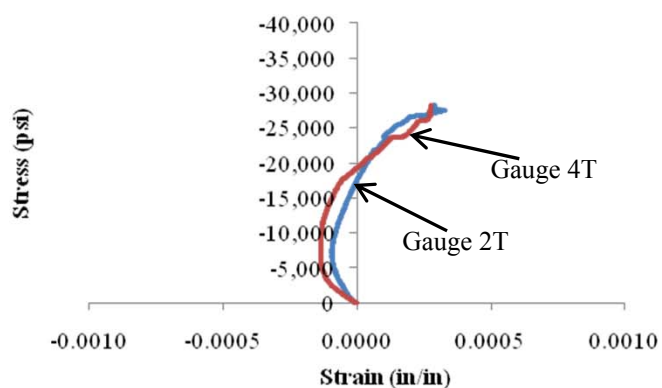
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00522 | -0.00237 | 3,501,316 | | | | |
| 2L | -0.00391 | -0.00163 | 4,362,021 | 2T | -0.00001 | -0.00009 | UD |
| 3L | -0.00621 | -0.00262 | 2,776,233 | | | | |
| 4L | -0.00373 | -0.00122 | 3,964,613 | 4T | -0.00007 | -0.00013 | UD |
| Average | | | 3,651,046 | | | | UD |

Stress-Strain Curve 140F_04_(09-03)_Long



Stress-Strain Curve 140F_04_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *ID represents insufficient data.

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT3-CX-05-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 21,111 lbs
 Compressive Strength, SC_x : 33,283 psi
 Compressive Modulus, E_x : 3,277,845 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : UD

Measured Specimen Dimensions:

Width, W: 1.0045 in
 Thickness, H: 0.7989 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,222 lbs
 50% Max Load: 10,556 lbs

PICTURE OF SPECIMEN PRE-TEST



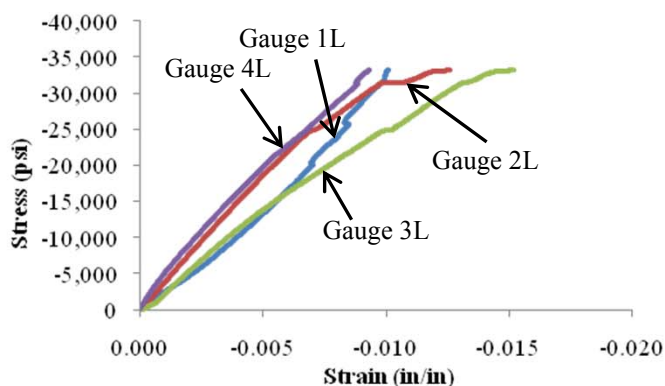
PICTURE OF SPECIMEN POST-TEST



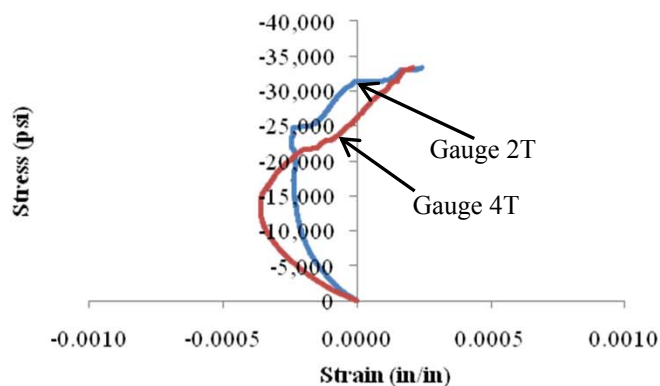
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00602 | -0.00276 | 3,060,487 | | | | |
| 2L | -0.00443 | -0.00172 | 3,689,016 | 2T | -0.00024 | -0.00017 | UD |
| 3L | -0.00616 | -0.00241 | 2,657,947 | | | | |
| 4L | -0.00407 | -0.00137 | 3,703,932 | 4T | -0.00033 | -0.00027 | UD |
| Average | | | 3,277,845 | | | | UD |

Stress-Strain Curve 140F_05_(09-03)_Long



Stress-Strain Curve 140F_05_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *ID represents insufficient data.

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

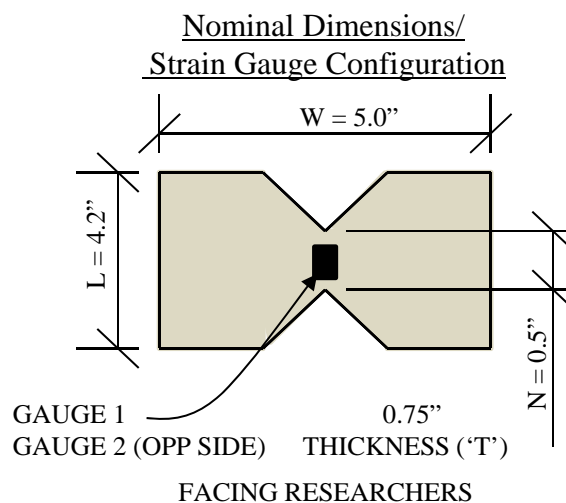
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-SXY-N40-FY09**
 Material: **3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **14,123** **lbs**
 Shear Strength, S_{xy} : **27,593** **psi**
 Shear Modulus, G_{xy} : **516,117** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT3-SXY-01-N40-FY09 | 13,985 | 27,400 | 453,264 | Shear |
| 2 | MAT3-SXY-02-N40-FY09 | 14,626 | 28,408 | 550,142 | Shear |
| 3 | MAT3-SXY-03-N40-FY09 | 14,202 | 28,145 | 607,483 | Shear |
| 4 | MAT3-SXY-04-N40-FY09 | 13,551 | 26,182 | 510,894 | Shear |
| 5 | MAT3-SXY-05-N40-FY09 | 14,252 | 27,831 | 458,803 | Shear |
| Average | | 14,123 | 27,593 | 516,117 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. S2-Glass fibers are oriented along the length of the specimen and along the width of the specimen. In addition, for this material, aramid fibers are oriented along the thickness. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets F-38 to F-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-01-N40-FY09
 Test Date: 4/2/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

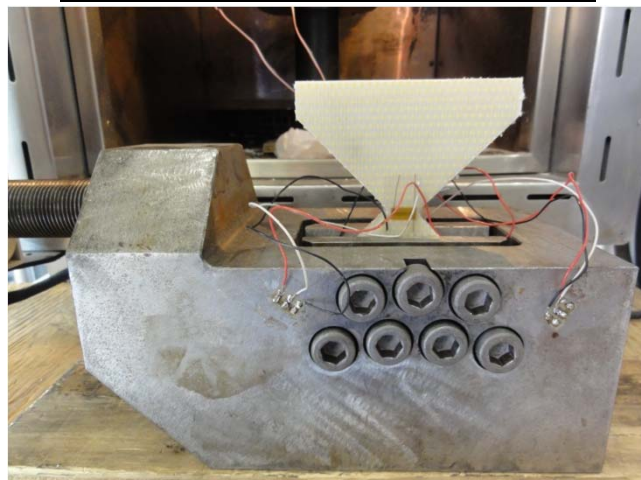
Average Material Properties:

Maximum Load, P_{max} : 13,985 lbs
 Shear Strength, S_{xy} : 27,400 psi
 Shear Modulus, G_{xy} : 453,264 psi

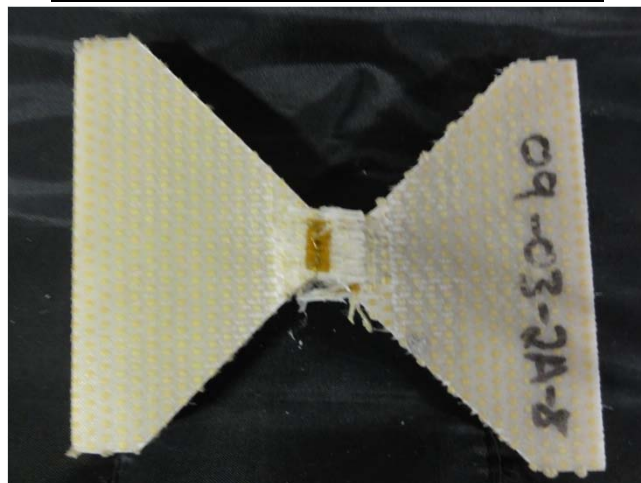
Measured Specimen Dimensions:

Thickness, T : 0.7757 in
 Notch Length, N : 0.6580 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,399 lbs
 20% Max Load: 2,797 lbs

PICTURE OF SPECIMEN PRE-TEST



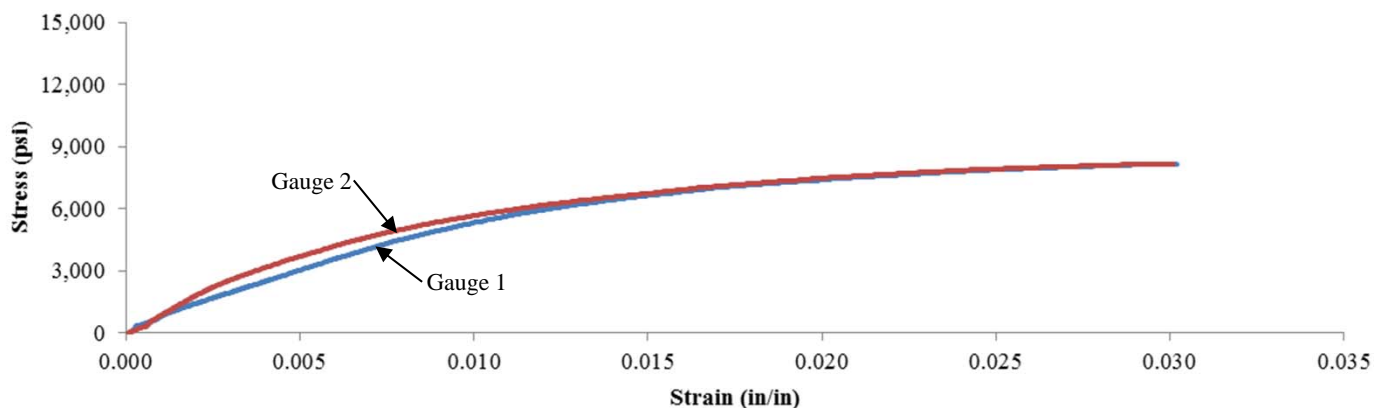
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01043 | 0.00442 | 456,222 |
| 2 | 0.00934 | 0.00326 | 450,305 |
| Average | | | 453,264 |

Stress-Strain Curve -40°F_1_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-02-N40-FY09
 Test Date: 4/3/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

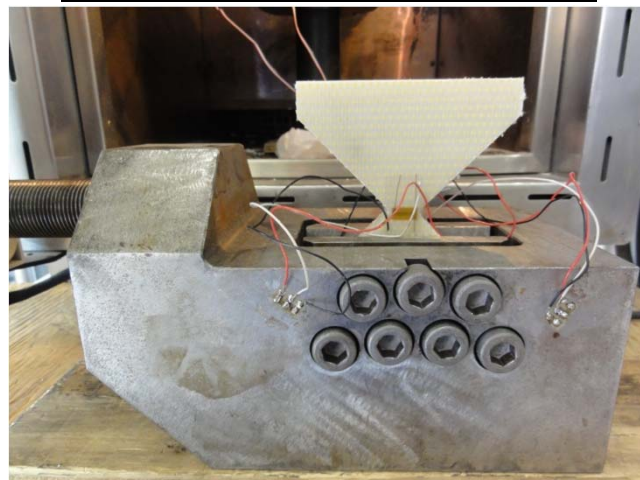
Average Material Properties:

Maximum Load, P_{max} : 14,626 lbs
 Shear Strength, S_{xy} : 28,408 psi
 Shear Modulus, G_{xy} : 550,142 psi

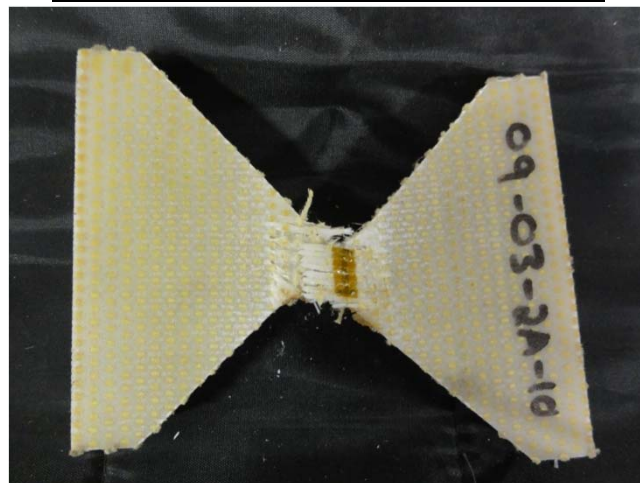
Measured Specimen Dimensions:

Thickness, T : 0.7789 in
 Notch Length, N : 0.6610 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,463 lbs
 20% Max Load: 2,925 lbs

PICTURE OF SPECIMEN PRE-TEST



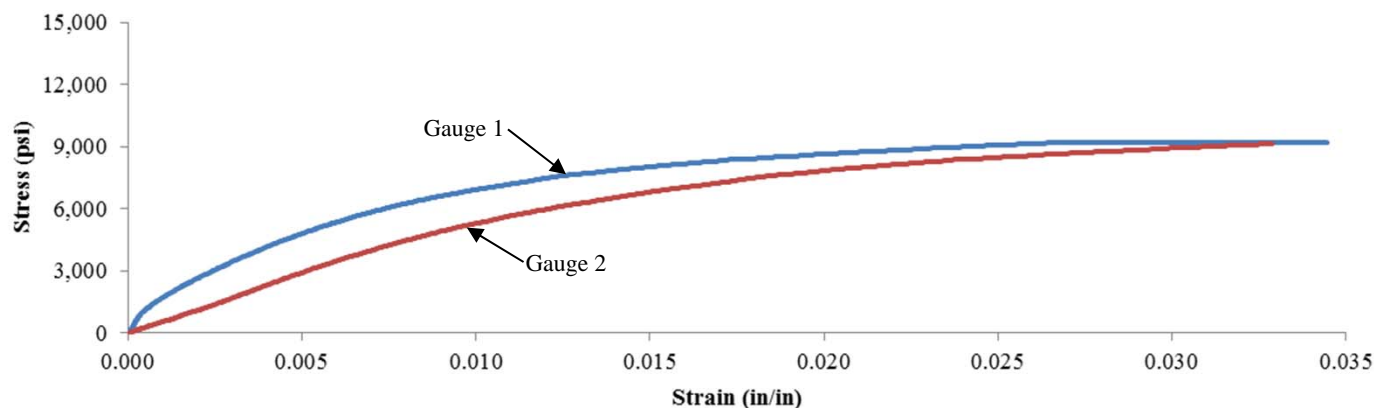
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00663 | 0.00222 | 644,391 |
| 2 | 0.01107 | 0.00484 | 455,893 |
| Average | | | 550,142 |

Stress-Strain Curve -40°F_2_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-03-N40-FY09
 Test Date: 4/5/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

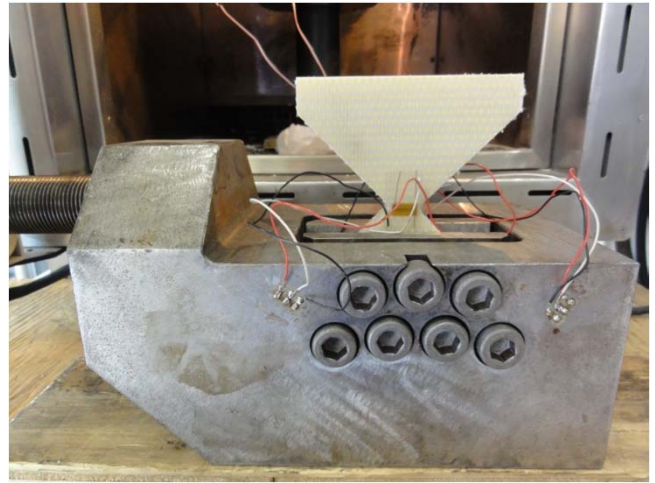
Average Material Properties:

Maximum Load, P_{max} : 14,202 lbs
 Shear Strength, S_{xy} : 28,145 psi
 Shear Modulus, G_{xy} : 607,483 psi

Measured Specimen Dimensions:

Thickness, T: 0.7634 in
 Notch Length, N: 0.6610 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,420 lbs
 20% Max Load: 2,840 lbs

PICTURE OF SPECIMEN PRE-TEST



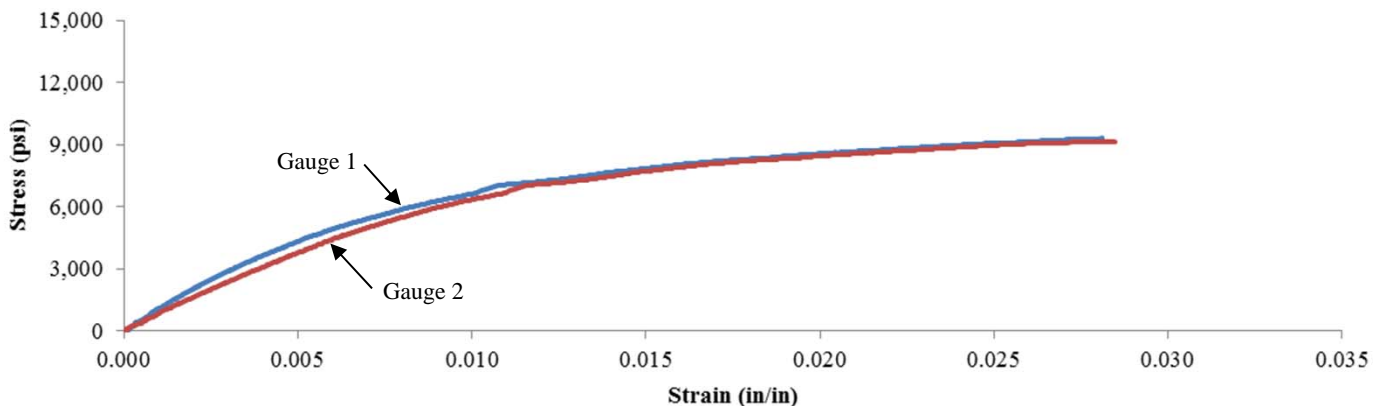
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00742 | 0.00285 | 615,859 |
| 2 | 0.00824 | 0.00354 | 599,107 |
| Average | | | 607,483 |

Stress-Strain Curve -40°F_3_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-04-N40-FY09
 Test Date: 4/9/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

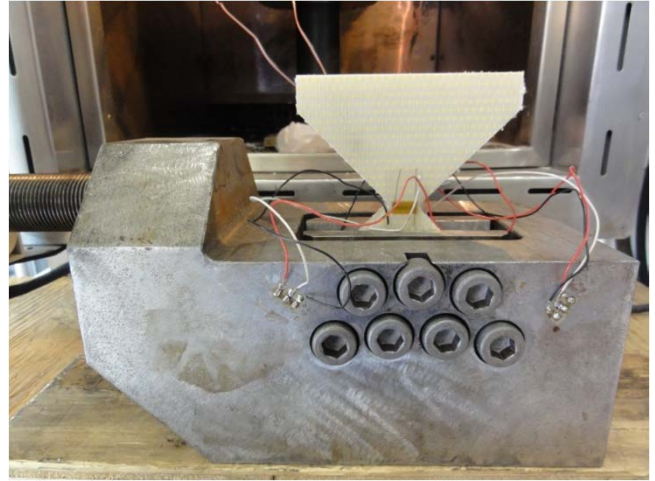
Average Material Properties:

Maximum Load, P_{max} : 13,551 lbs
 Shear Strength, S_{xy} : 26,182 psi
 Shear Modulus, G_{xy} : 510,894 psi

Measured Specimen Dimensions:

Thickness, T : 0.7830 in
 Notch Length, N : 0.6610 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,355 lbs
 20% Max Load: 2,710 lbs

PICTURE OF SPECIMEN PRE-TEST



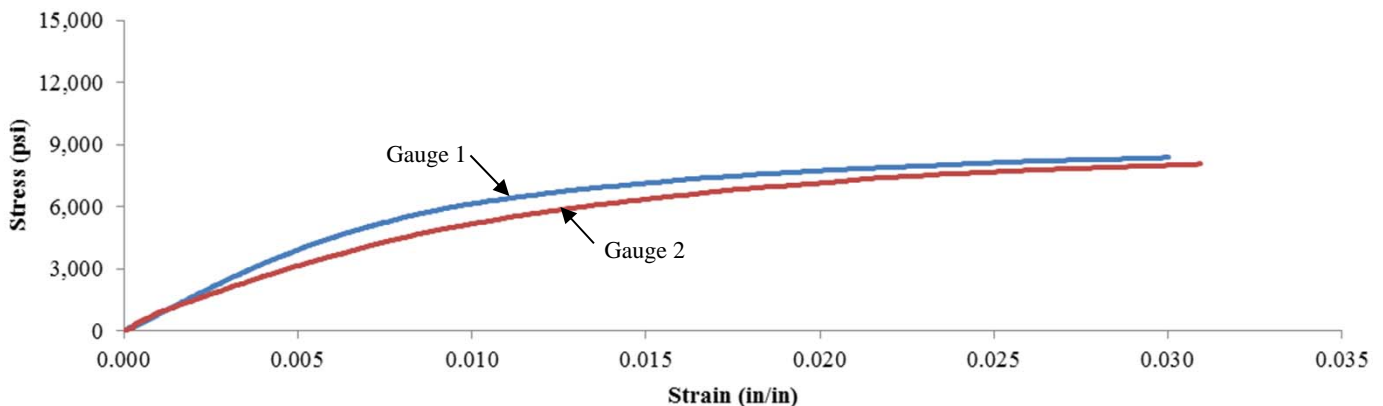
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00745 | 0.00311 | 603,142 |
| 2 | 0.01019 | 0.00393 | 418,647 |
| Average | | | 510,894 |

Stress-Strain Curve -40°F_4_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-05-N40-FY09
 Test Date: 4/12/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

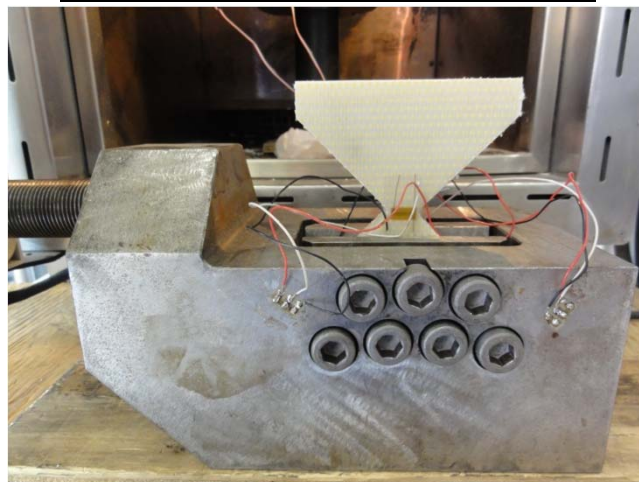
Average Material Properties:

Maximum Load, P_{max} : 14,252 lbs
 Shear Strength, S_{xy} : 27,831 psi
 Shear Modulus, G_{xy} : 458,803 psi

Measured Specimen Dimensions:

Thickness, T : 0.7759 in
 Notch Length, N : 0.6600 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,425 lbs
 20% Max Load: 2,850 lbs

PICTURE OF SPECIMEN PRE-TEST



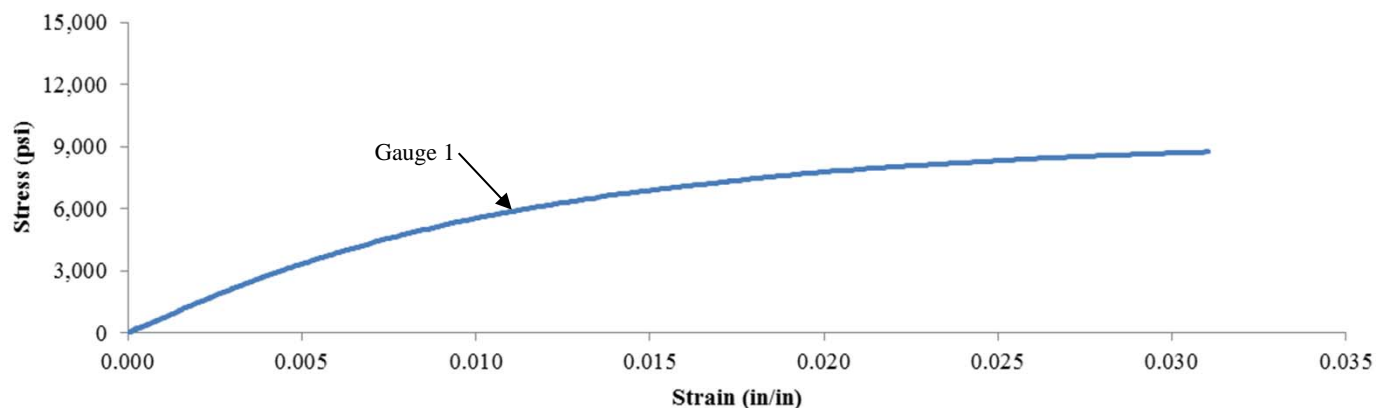
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01007 | 0.00400 | 458,803 |
| 2 | Lost | Gauge | LG |
| Average | | | 458,803 |

Stress-Strain Curve -40°F_5_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

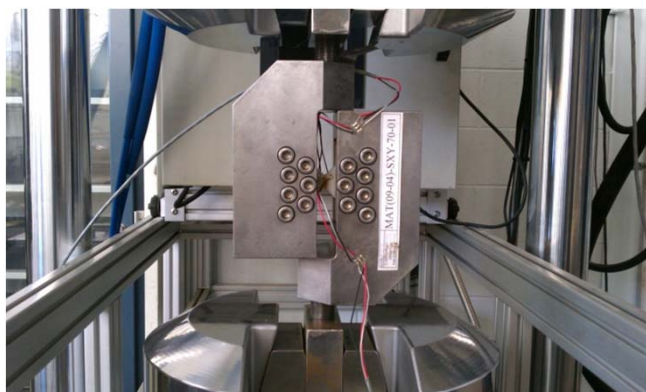
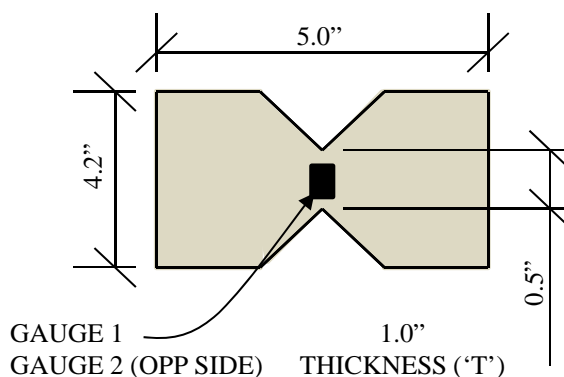
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-SXY-70-FY09**
 Material: **3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **11,992** **lbs**
 Shear Strength, S_{xy} : **23,339** **psi**
 Shear Modulus, G_{xy} : **415,404** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT3-SXY-01-70-FY09 | 12,024 | 23,150 | 375,513 | Shear |
| 2 | MAT3-SXY-02-70-FY09 | 12,461 | 24,710 | 376,646 | Shear |
| 3 | MAT3-SXY-03-70-FY09 | 11,986 | 23,005 | 469,808 | Shear |
| 4 | MAT3-SXY-04-70-FY09 | 12,087 | 23,375 | 420,843 | Shear |
| 5 | MAT3-SXY-05-70-FY09 | 11,403 | 22,455 | 434,211 | Shear |
| Average | | 11,992 | 23,339 | 415,404 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. S2-Glass fibers are oriented along the length of the specimen and along the width of the specimen. In addition, for this material, aramid fibers are oriented along the thickness. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS****Notes:**

- 1) Individual specimen results are shown on Sheets F-44 to F-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-01-70-FY09
 Test Date: 01/24/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,024 lbs
 Shear Strength, S_{xy} : 23,150 psi
 Shear Modulus, G_{xy} : 1,509,795 psi

Measured Specimen Dimensions:

Thickness, T: 0.7846 in
 Notch Length, N: 0.662 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,202 lbs
 20% Max Load: 2,405 lbs

PICTURE OF SPECIMEN PRE-TEST



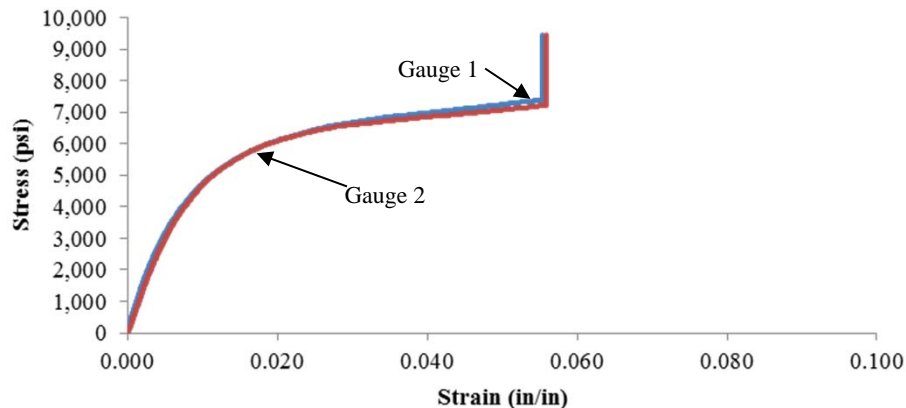
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00946 | 0.00320 | 369,620 |
| 2 | 0.00972 | 0.00365 | 381,406 |
| Average | | | 375,513 |

Stress-Strain Curve 70F_01_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-02-70-FY09
 Test Date: 01/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,461 lbs
 Shear Strength, S_{xy} : 24,710 psi
 Shear Modulus, G_{xy} : 376,646 psi

Measured Specimen Dimensions:

Thickness, T : 0.7664 in
 Notch Length, N : 0.658 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,246 lbs
 20% Max Load: 2,492 lbs

PICTURE OF SPECIMEN PRE-TEST



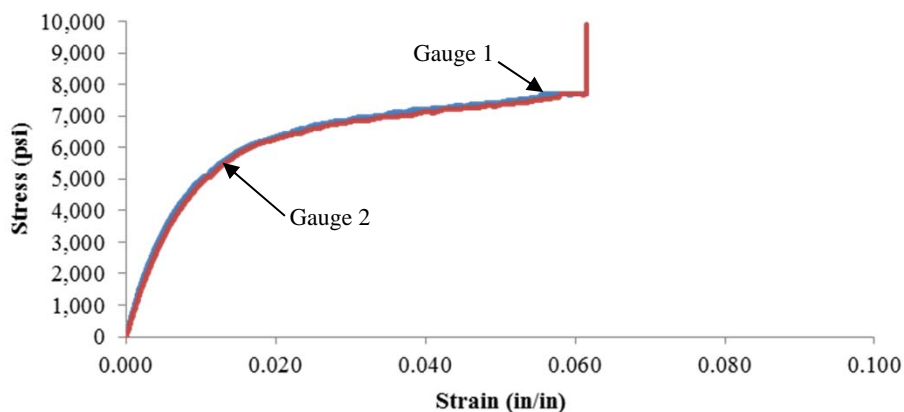
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00968 | 0.00324 | 383,710 |
| 2 | 0.01033 | 0.00364 | 369,582 |
| Average | | | 376,646 |

Stress-Strain Curve 70F_02_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-03-70-FY09
 Test Date: 01/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,986 lbs
 Shear Strength, S_{xy} : 23,005 psi
 Shear Modulus, G_{xy} : 469,808 psi

Measured Specimen Dimensions:

Thickness, T: 0.7907 in
 Notch Length, N: 0.659 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,199 lbs
 20% Max Load: 2,397 lbs

PICTURE OF SPECIMEN PRE-TEST



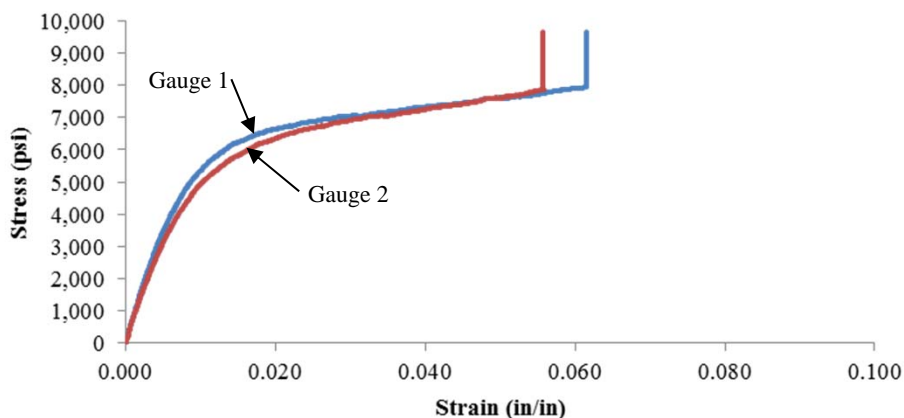
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00753 | 0.00304 | 512,014 |
| 2 | 0.00882 | 0.00344 | 427,603 |
| Average | | | 469,808 |

Stress-Strain Curve 70F_03_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-04-70-FY09
 Test Date: 01/31/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,087 lbs
 Shear Strength, S_{xy} : 23,375 psi
 Shear Modulus, G_{xy} : 420,843 psi

Measured Specimen Dimensions:

Thickness, T: 0.7835 in
 Notch Length, N: 0.660 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,209 lbs
 20% Max Load: 2,417 lbs

PICTURE OF SPECIMEN PRE-TEST



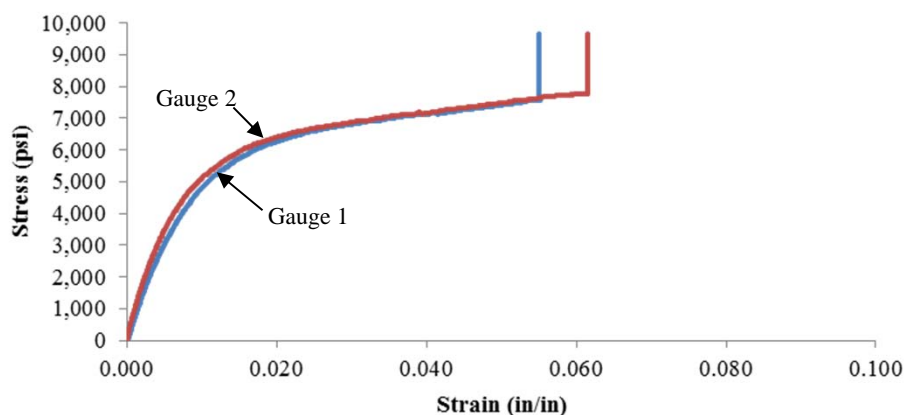
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00944 | 0.00360 | 400,107 |
| 2 | 0.00819 | 0.00289 | 441,580 |
| Average | | | 420,843 |

Stress-Strain Curve 70F_04_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-05-70-FY09
 Test Date: 01/31/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 11,403 lbs
 Shear Strength, S_{xy} : 22,455 psi
 Shear Modulus, G_{xy} : 434,211 psi

Measured Specimen Dimensions:

Thickness, T : 0.7706 in
 Notch Length, N : 0.659 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,140 lbs
 20% Max Load: 2,281 lbs

PICTURE OF SPECIMEN PRE-TEST



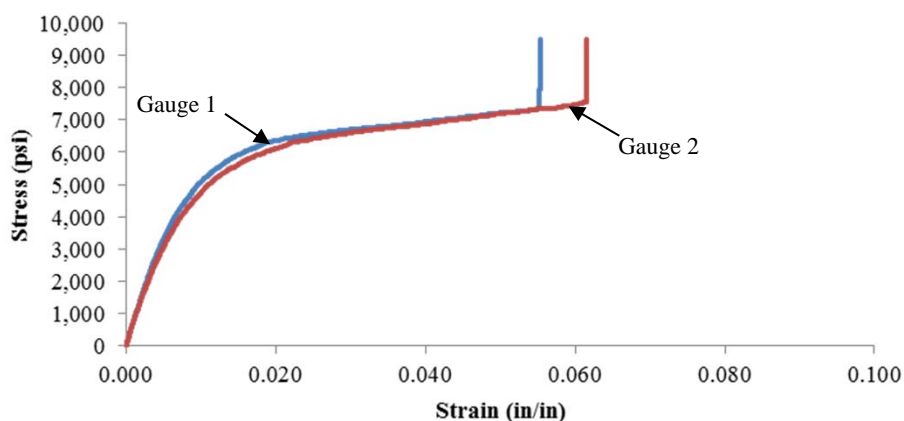
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00788 | 0.00309 | 468,239 |
| 2 | 0.00896 | 0.00334 | 400,183 |
| Average | | | 434,211 |

Stress-Strain Curve 70F_05_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

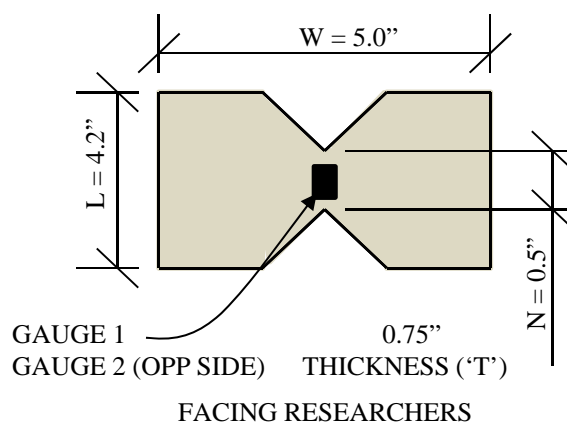
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-SXY-140-FY09**
 Material: **3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **10,444** **lbs**
 Shear Strength, S_{xy} : **20,339** **psi**
 Shear Modulus, G_{xy} : **268,588** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT3-SXY-01-140-FY09 | 10,209 | 20,352 | 249,095 | Shear |
| 2 | MAT3-SXY-02-140-FY09 | 10,561 | 20,580 | 278,557 | Shear |
| 3 | MAT3-SXY-03-140-FY09 | 10,578 | 20,504 | 261,399 | Shear |
| 4 | MAT3-SXY-04-140-FY09 | 10,204 | 19,455 | 245,657 | Shear |
| 5 | MAT3-SXY-05-140-FY09 | 10,668 | 20,806 | 308,233 | Shear |
| Average | | 10,444 | 20,339 | 268,588 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. S2-Glass fibers are oriented along the length of the specimen and along the width of the specimen. In addition, for this material, aramid fibers are oriented along the thickness. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets F-50 to F-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-01-140-FY09
 Test Date: 3/12/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

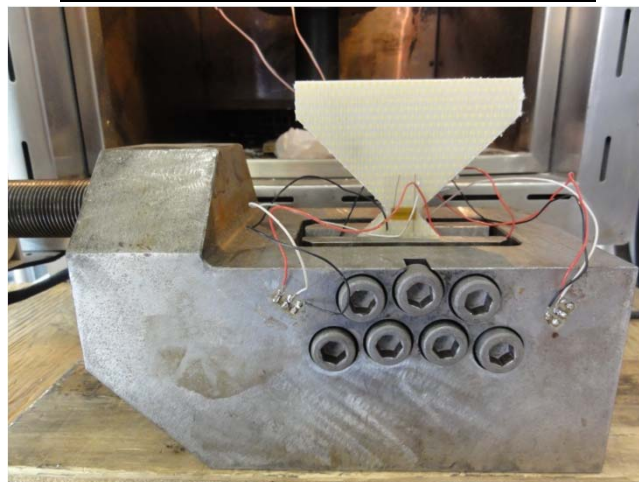
Average Material Properties:

Maximum Load, P_{max} : 10,209 lbs
 Shear Strength, S_{xy} : 20,352 psi
 Shear Modulus, G_{xy} : 249,095 psi

Measured Specimen Dimensions:

Thickness, T: 0.7612 in
 Notch Length, N: 0.6590 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,021 lbs
 20% Max Load: 2,042 lbs

PICTURE OF SPECIMEN PRE-TEST



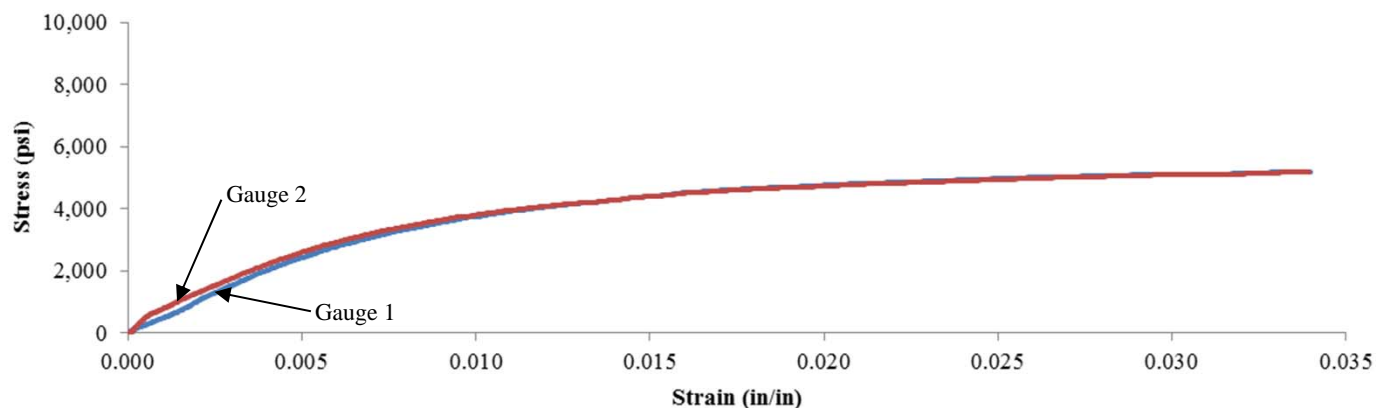
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01206 | 0.00402 | 253,219 |
| 2 | 0.01188 | 0.00357 | 244,971 |
| Average | | | 249,095 |

Stress-Strain Curve 140°F_1_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-02-140-FY09
 Test Date: 3/12/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

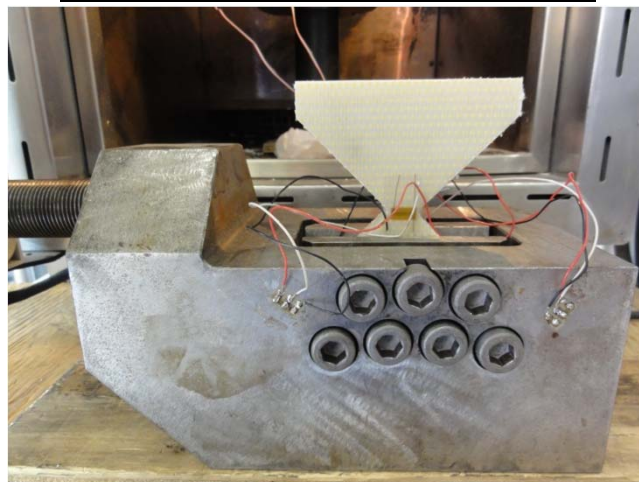
Average Material Properties:

Maximum Load, P_{max} : 10,561 lbs
 Shear Strength, S_{xy} : 20,580 psi
 Shear Modulus, G_{xy} : 278,557 psi

Measured Specimen Dimensions:

Thickness, T : 0.7787 in
 Notch Length, N : 0.6590 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,056 lbs
 20% Max Load: 2,112 lbs

PICTURE OF SPECIMEN PRE-TEST



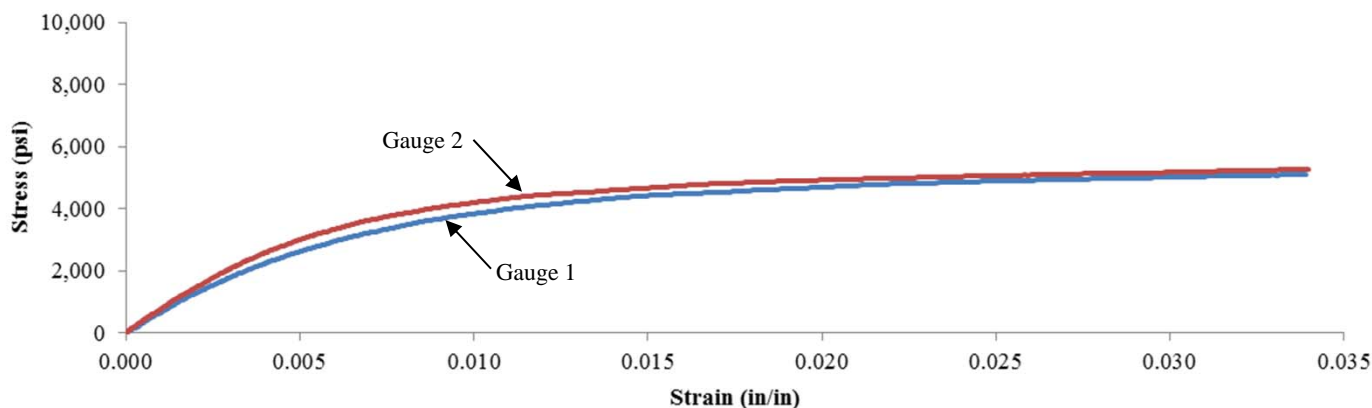
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01204 | 0.00355 | 242,405 |
| 2 | 0.00949 | 0.00295 | 314,709 |
| Average | | | 278,557 |

Stress-Strain Curve 140°F_2_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-03-140-FY09
 Test Date: 3/13/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

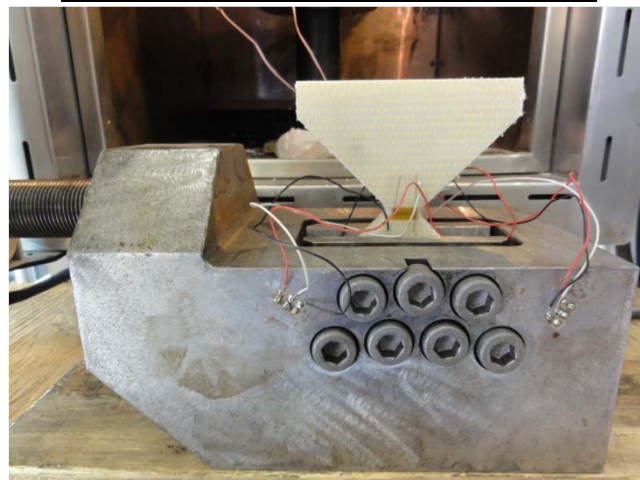
Average Material Properties:

Maximum Load, P_{max} : 10,578 lbs
 Shear Strength, S_{xy} : 20,504 psi
 Shear Modulus, G_{xy} : 261,399 psi

Measured Specimen Dimensions:

Thickness, T : 0.7781 in
 Notch Length, N : 0.6630 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,058 lbs
 20% Max Load: 2,116 lbs

PICTURE OF SPECIMEN PRE-TEST



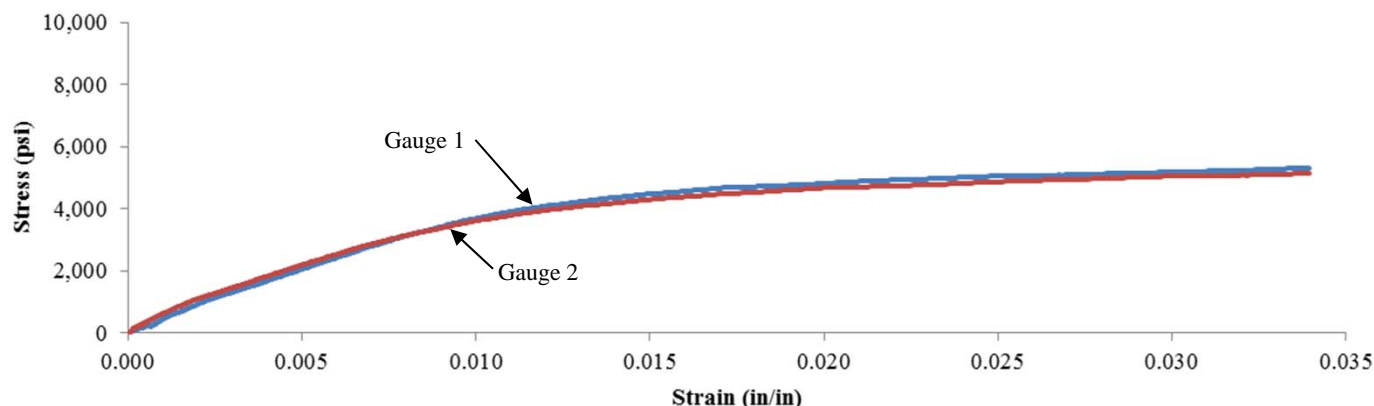
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01217 | 0.00498 | 285,186 |
| 2 | 0.01323 | 0.00460 | 237,613 |
| Average | | | 261,399 |

Stress-Strain Curve 140°F_3_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-04-140-FY09
 Test Date: 3/14/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

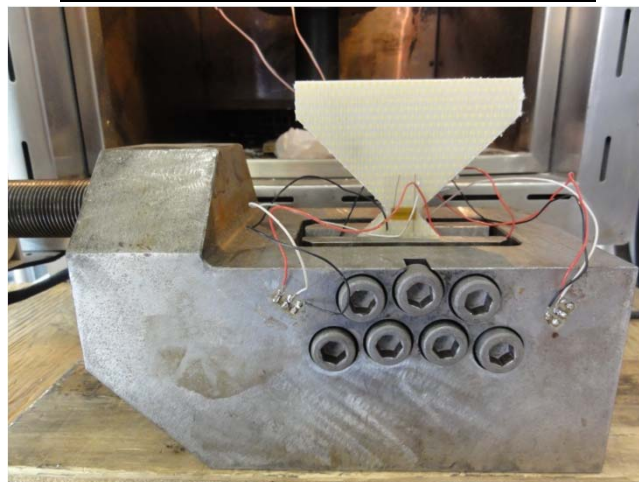
Average Material Properties:

Maximum Load, P_{max} : 10,204 lbs
 Shear Strength, S_{xy} : 19,455 psi
 Shear Modulus, G_{xy} : 245,657 psi

Measured Specimen Dimensions:

Thickness, T : 0.7875 in
 Notch Length, N : 0.6660 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,020 lbs
 20% Max Load: 2,041 lbs

PICTURE OF SPECIMEN PRE-TEST



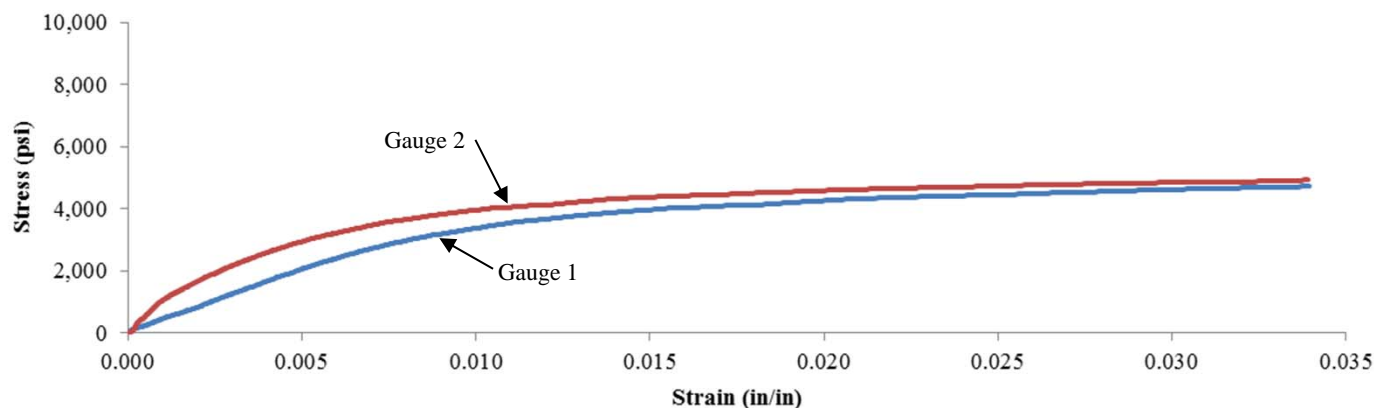
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01401 | 0.00471 | 209,065 |
| 2 | 0.00943 | 0.00254 | 282,249 |
| Average | | | 245,657 |

Stress-Strain Curve 140°F_4_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXY-05-140-FY09
 Test Date: 3/15/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

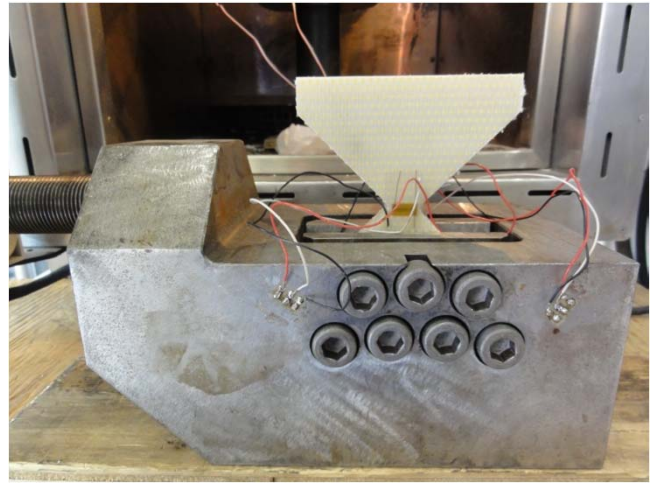
Average Material Properties:

Maximum Load, P_{max} : 10,668 lbs
 Shear Strength, S_{xy} : 20,806 psi
 Shear Modulus, G_{xy} : 308,233 psi

Measured Specimen Dimensions:

Thickness, T : 0.7722 in
 Notch Length, N : 0.6640 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 10% Max Load: 1,067 lbs
 20% Max Load: 2,134 lbs

PICTURE OF SPECIMEN PRE-TEST



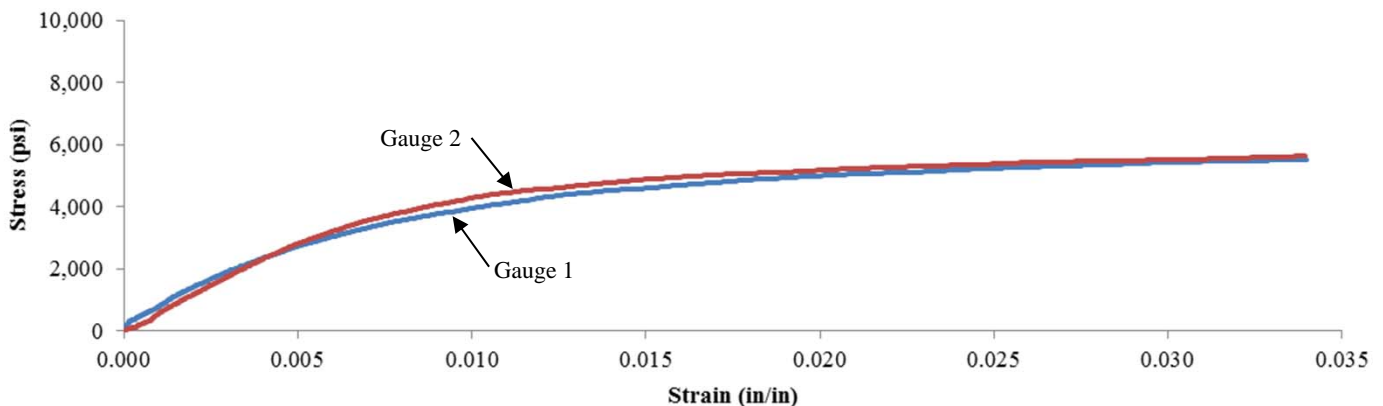
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 20% Max load (in/in) | Strain @ 10% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01124 | 0.00334 | 263,624 |
| 2 | 0.00943 | 0.00354 | 352,843 |
| Average | | | 308,233 |

Stress-Strain Curve 140°F_5_(09-03)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 10% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS – AVERAGE OF 5 FRACTURE SPECS. OR ELASTIC SPECS.

Specimen ID Group: MAT3-TZ-N40-FY09

Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber

Nominal Temperature: -40°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Tensile Strength, ST_z : 7,742 psi (Obtained with Fracture Tests)

Tensile Modulus, E_z : 1,771,241 psi (Obtained with Elastic Tests)

| ELASTIC MODULUS RESULTS | | |
|-------------------------|---------------------------|------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Modulus, E_z (psi) |
| MAT3-TZE-1-N40-FY09 | 1,526 | 1,614,236 |
| MAT3-TZE-2-N40-FY09 | 1,288 | 1,823,493 |
| MAT3-TZE-3-N40-FY09 | 1,526 | 1,982,836 |
| MAT3-TZE-4-N40-FY09 | 1,580 | 1,625,675 |
| MAT3-TZE-5-N40-FY09 | 1,089 | 1,809,966 |
| Average | | 1,771,241 |

| ULTIMATE STRENGTH RESULTS | | |
|---------------------------|---------------------------|--------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) |
| MAT3-TZF-1-N40-FY09 | 3,632 | 7,780 |
| MAT3-TZF-2-N40-FY09 | 3,709 | 7,944 |
| MAT3-TZF-3-N40-FY09 | 3,769 | 8,094 |
| MAT3-TZF-4-N40-FY09 | 3,513 | 7,584 |
| MAT3-TZF-5-N40-FY09 | 3,377 | 7,308 |
| Average | | 7,742 |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The glass fiber laminates are orientated along two axes known as the x and y-axes. Aramid fibers are oriented to resist tension force along the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimens consist of a cylinder with a reduced gauge section. This test is performed on the Instron 8502A. A universal joint is attached above and below the specimen to allow uniaxial tension.

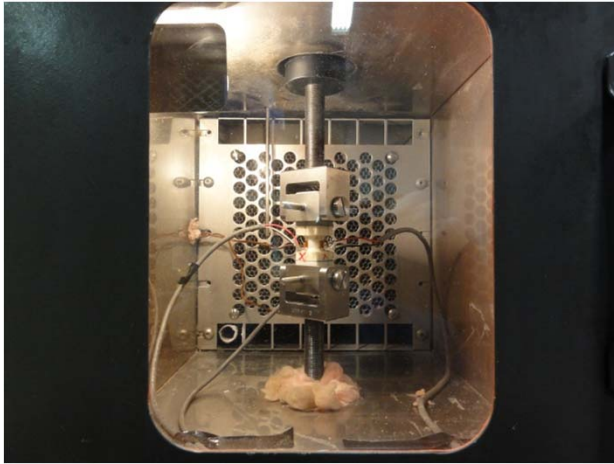
The material properties are tested using two groups of specimens for this material only. The elastic modulus is measured using the “Elastic Test”. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown on the next page. The average elastic modulus as interpreted from the three strain gauges is reported in the table above. The nomenclature to identify the specimens used to measure the elastic modulus consists of “TZE” to differentiate between the specimens used to measure the ultimate stress. These specimens could not be used to measure the ultimate strength as failures occur at the bondline.

The ultimate strength is measured using the “Fracture Test”. The specimen geometry required to ensure that fracture does not occur at the bondline is used for this test. However, the gauge length (very small, 0.01 in.) disallows the application of strain gauges. In order to further ensure that failure does not occur due to high tensile stresses at the bondline, each bondline is clamped using the fixtures (top and bottom) shown in the next sheet which creates an initial compression force on the bondline. The fixture also attaches to the test frame and applies the tension force by contact at the end of the reduced section. This is illustrated by a free body diagram of the test setup which identifies the internal forces at the bondline and the internal forces in the reduced section. The clamping force is required to ensure the fixture does not open upon tension loading and is applied by tightening the bolts that are part of the fixture. The approximate magnitude is 1600 lbs. One side of the fixture attaches to the end of the specimen and the other flares around the transition area as indicated by the location on the next sheet. More information in regards to the fixture can be found in the project final report. The nomenclature to identify the specimens used to measure the ultimate strength consists of “TZF” to differentiate between the specimens used to measure the elastic modulus. Please see diagrams and pictures of the test setup on next page for more information:

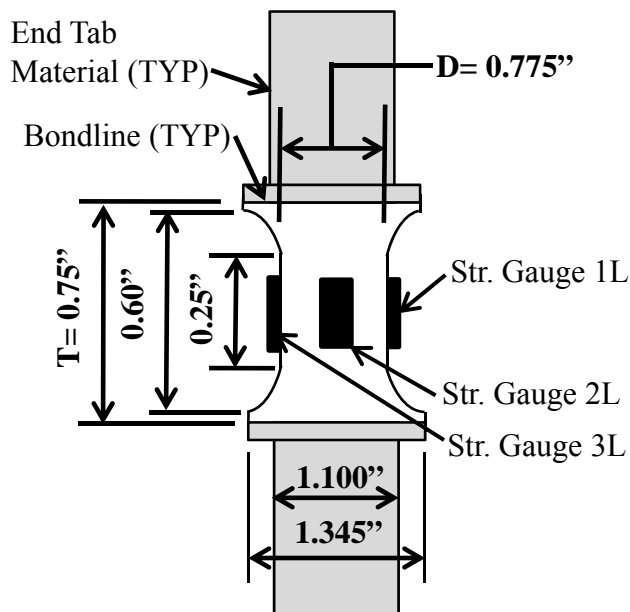
MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

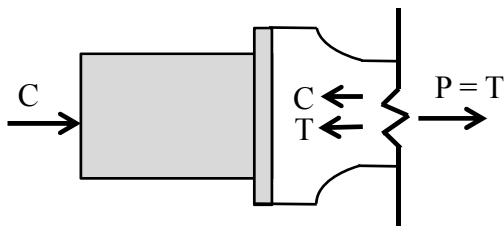
Elastic Test: -40°F Test Condition



Elastic Test Specimen Dimensions/
Strain Gauge Configuration/Front View



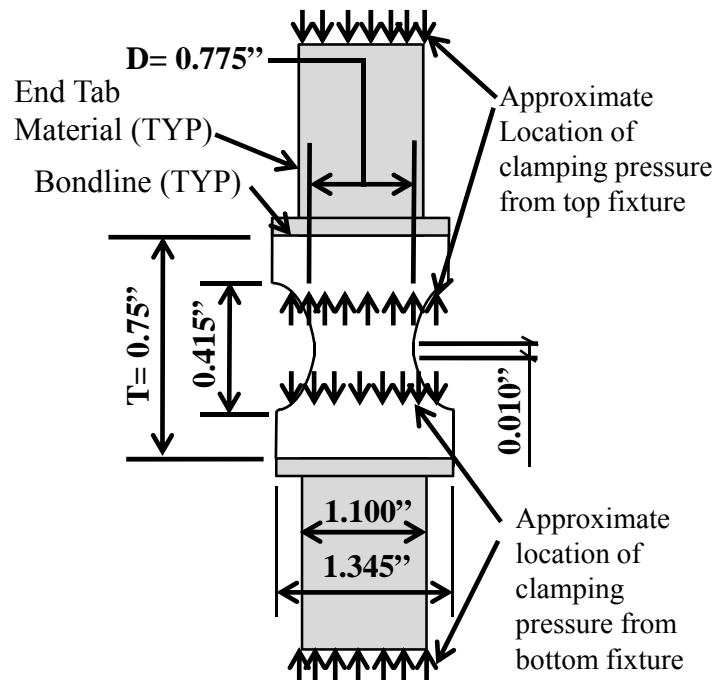
Free Body Diagram, Force in Test Area



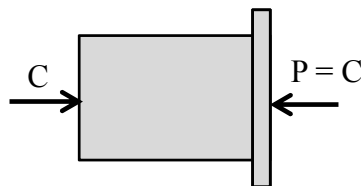
Fracture Test: -40°F Test Condition



Fracture Test Specimen Dimensions



Free Body Diagram, Force in Bondline



P = Internal Force
 C = Initial Compression from Clamping Force
 T = Force from Testing Machine. Introduced into specimen at the pt. where the fixture houses the base of the reduced section.

Notes:

- 1) Reference F-57 to F-61 for a summary of the specimen results for the “Elastic Tests”.
- 2) Reference F-62 to F-66 for a summary of the specimen results for the “Fracture Tests”.
- 3) All “Elastic Test” specimens fail at the bondline and all “Fracture Test” specimens fail by rupture in the reduced section.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-1-N40-FY09**
 Test Date: 8/6/2012
 Specimen Received: 8/17/2012
 Properties Measured: E_z

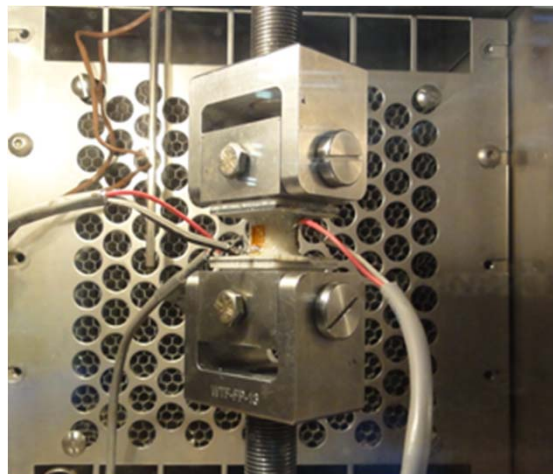
Average Material Properties:

Maximum Load, P_z : 1,526 lbs
 Tensile Modulus, E_z : 1,614,236 psi

Measured Specimen Dimensions:

Diameter, D : 0.691 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 2,710 psi
 **10% Max Stress: 774 psi

PICTURE OF SPECIMEN PRE-TEST

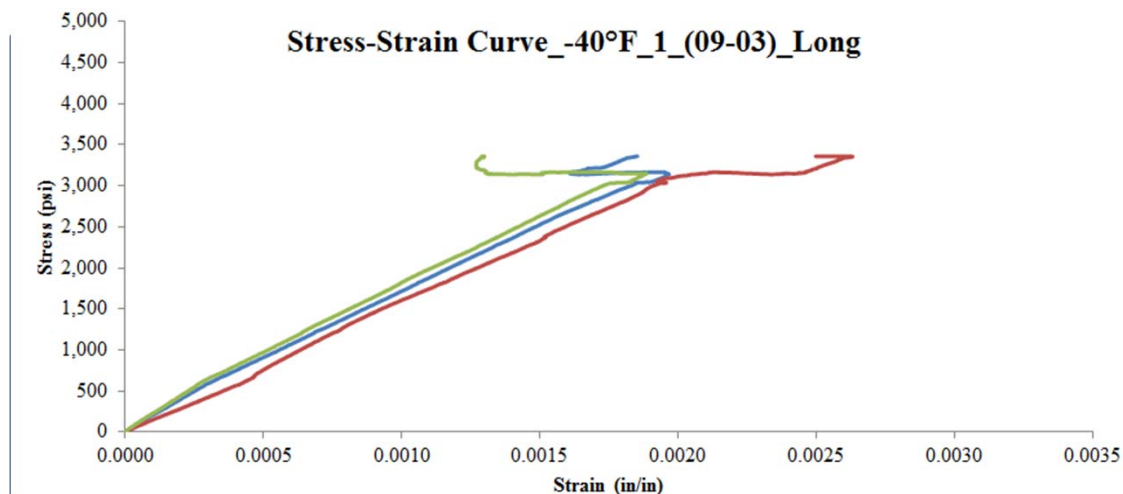


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001618 | 0.000413 | 1,607,204 |
| 2L | 0.001733 | 0.000507 | 1,578,515 |
| 3L | 0.001546 | 0.000378 | 1,656,988 |
| Average | | | 1,614,236 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at -40 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-2-N40-FY09**
 Test Date: 8/6/2012
 Specimen Received: 8/16/2012
 Properties Measured: E_z

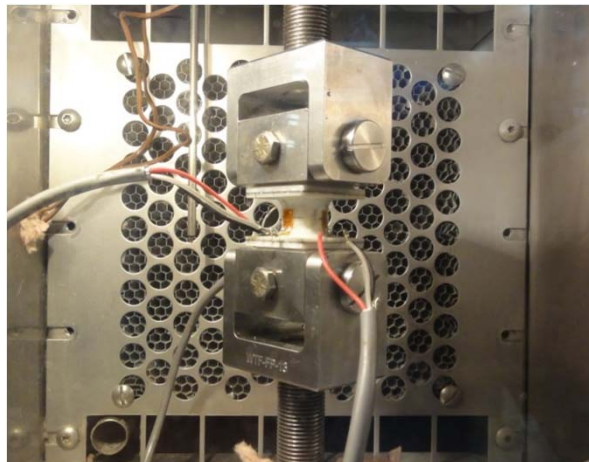
Average Material Properties:

Maximum Load, P_z : 1,288 lbs
 Tensile Modulus, E_z : 1,823,493 psi

Measured Specimen Dimensions:

Diameter, D : 0.690 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 2,710 psi
 **10% Max Stress: 774 psi

PICTURE OF SPECIMEN PRE-TEST

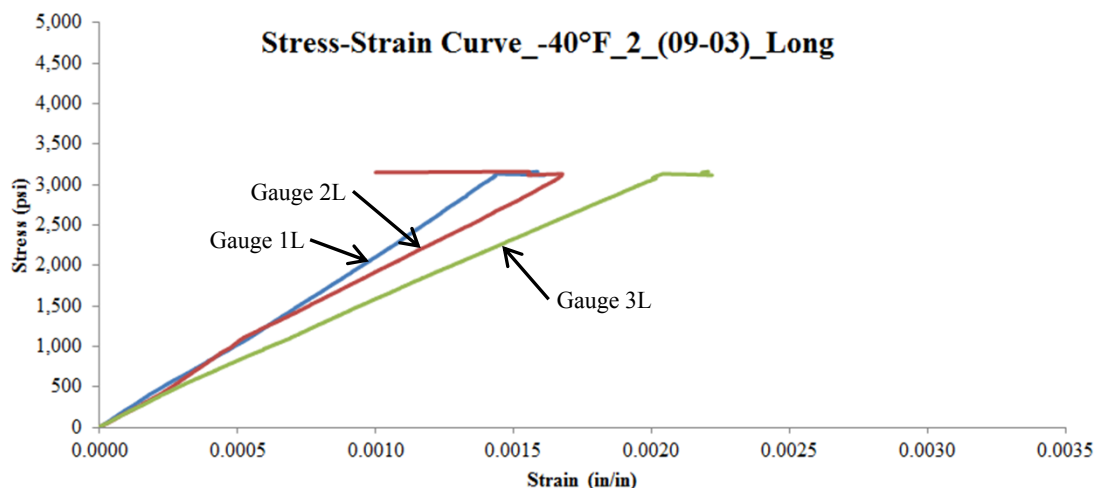


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001260 | 0.000373 | 2,180,686 |
| 2L | 0.001458 | 0.000379 | 1,793,841 |
| 3L | 0.001759 | 0.000465 | 1,495,951 |
| Average | | | 1,823,493 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at -40 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-3-N40-FY09**
 Test Date: 8/6/2012
 Specimen Received: 8/16/2012
 Properties Measured: E_z

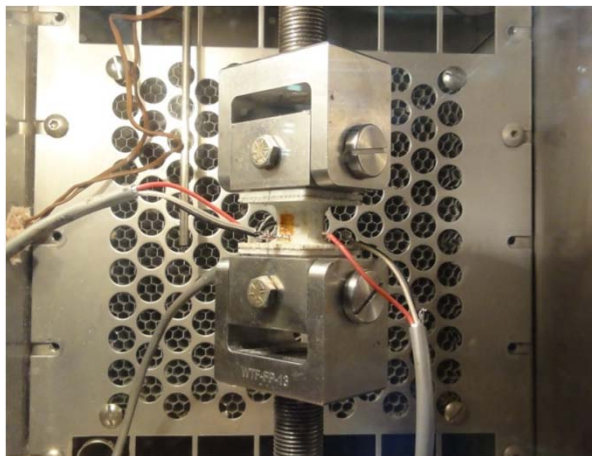
Average Material Properties:

Maximum Load, P_z : 1,526 lbs
 Tensile Modulus, E_z : 1,982,836 psi

Measured Specimen Dimensions:

Diameter, D : 0.688 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 2,710 psi
 **10% Max Stress: 774 psi

PICTURE OF SPECIMEN PRE-TEST

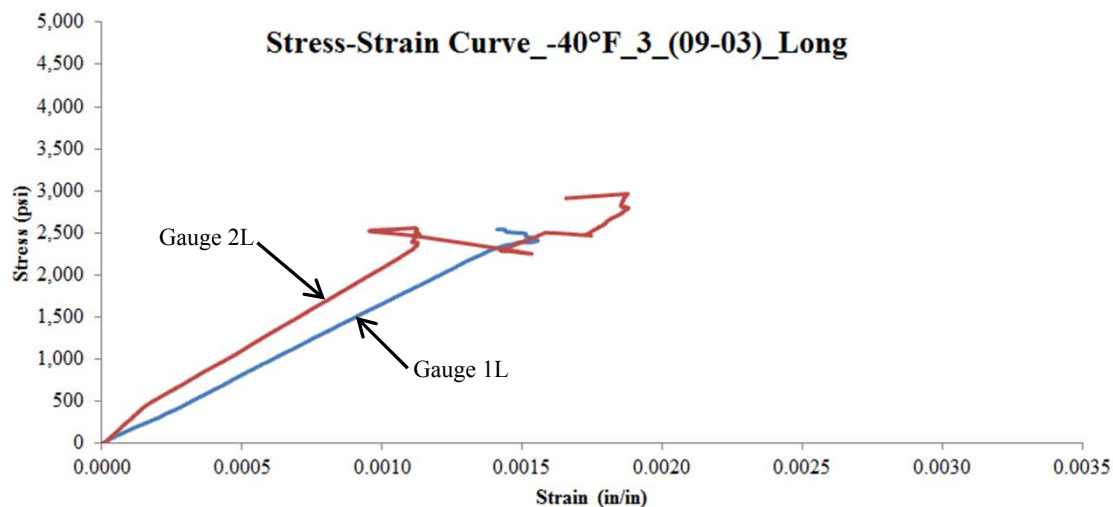


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001196 | 0.000476 | 2,688,813 |
| 2L | 0.001841 | 0.000325 | 1,276,860 |
| 3L | Lost Gauge | | |
| Average | | | 1,982,836 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at -40 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-4-N40-FY09**
 Test Date: 8/6/2012
 Specimen Received: 8/17/2012
 Properties Measured: E_z

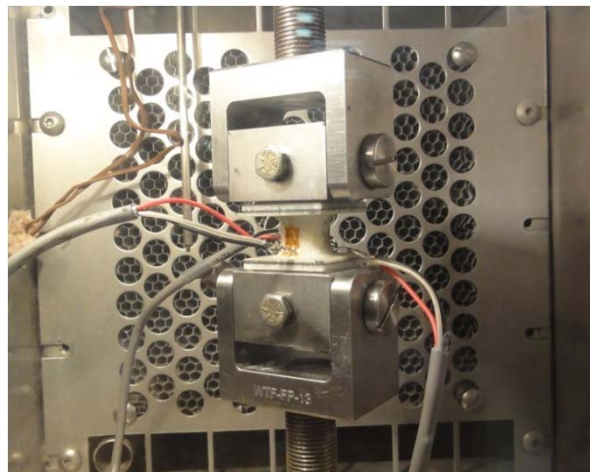
Average Material Properties:

Maximum Load, P_z : 1,580 lbs
 Tensile Modulus, E_z : 1,625,675 psi

Measured Specimen Dimensions:

Diameter, D : 0.685 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 2,710 psi
 **10% Max Stress: 774 psi

PICTURE OF SPECIMEN PRE-TEST

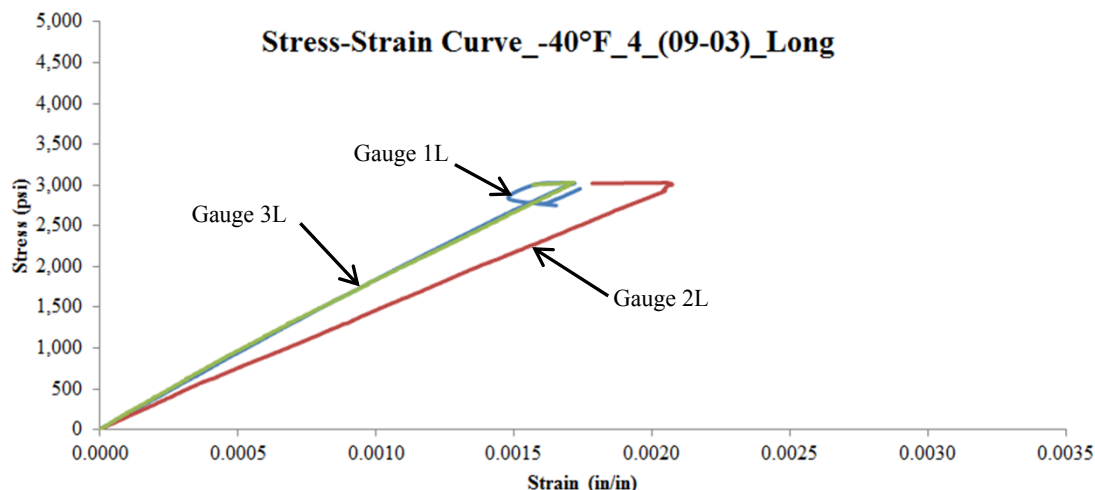


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001512 | 0.000409 | 1,755,326 |
| 2L | 0.001885 | 0.000514 | 1,411,408 |
| 3L | 0.001525 | 0.000394 | 1,710,291 |
| Average | | | 1,625,675 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at -40 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-5-N40-FY09**
 Test Date: 8/6/2012
 Specimen Received: 8/17/2012
 Properties Measured: E_z

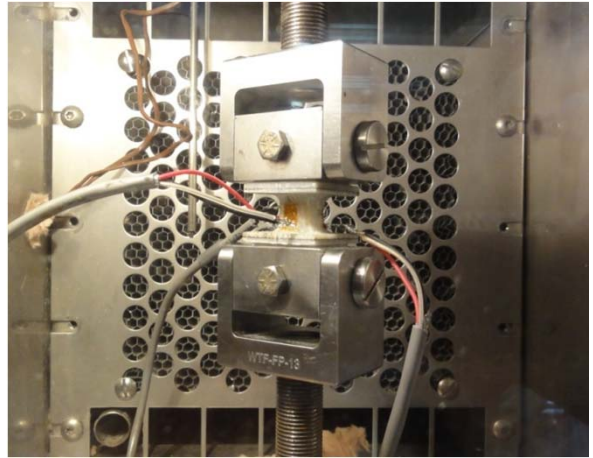
Average Material Properties:

Maximum Load, P_z : 1,089 lbs
 Tensile Modulus, E_z : 1,809,966 psi

Measured Specimen Dimensions:

Diameter, D: 0.692 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 2,710 psi
 **10% Max Stress: 774 psi

PICTURE OF SPECIMEN PRE-TEST

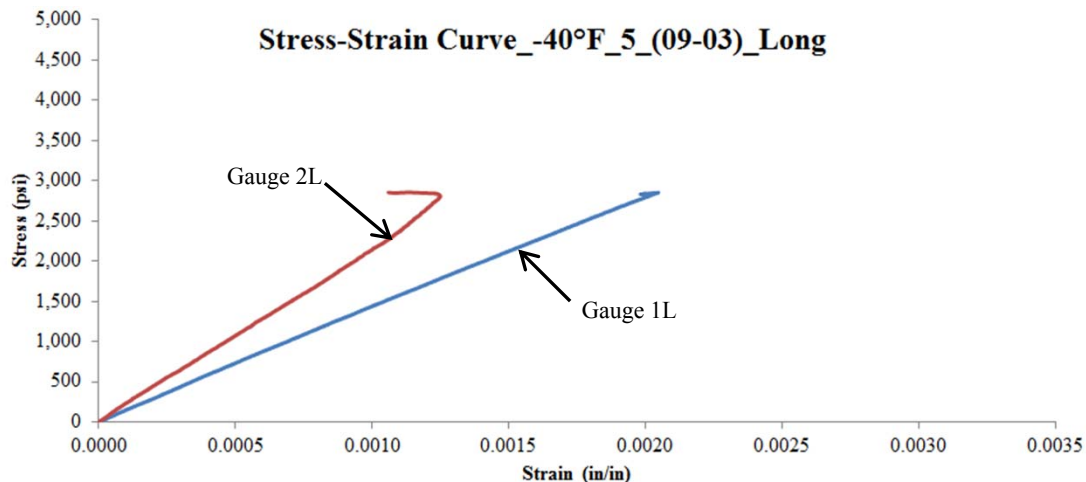


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001938 | 0.000528 | 1,372,513 |
| 2L | 0.001220 | 0.000359 | 2,247,418 |
| 3L | Lost Gauge | | |
| Average | | | 1,809,966 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at -40 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)**FRACTURE TEST SUMMARY**

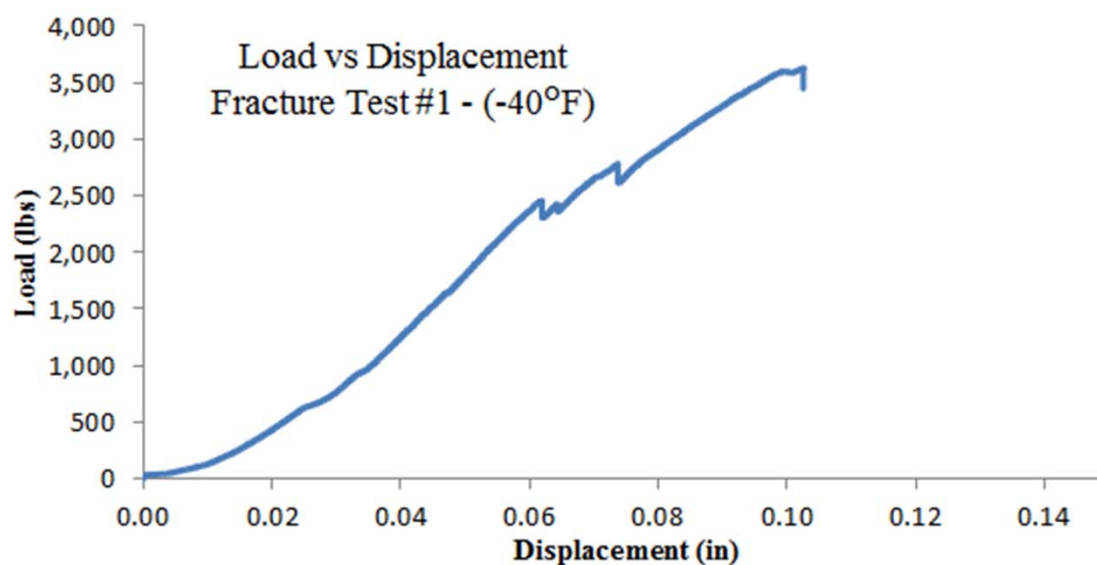
Specimen ID: **MAT3-TZF-1-N40-FY09**
Test Date: 8/13/2012
Specimen Received: 8/6/2012
Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 3,632 lbs
Tensile Strength, ST_z : 7,780 psi

Measured Specimen Dimensions:

Diameter, D: 0.771 in
Laboratory Temperature: 68°F
Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST**PICTURE OF SPECIMEN POST-TEST****Engineering Test notes:**

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-2-N40-FY09**
 Test Date: 8/13/2012
 Specimen Received: 8/6/2012
 Properties Measured: ST_z

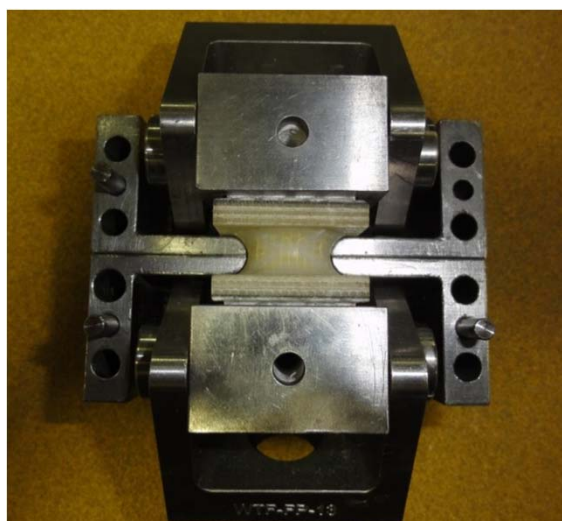
Material Properties:

Maximum Load, P_z : 3,709 lbs
 Tensile Strength, ST_z : 7,944 psi

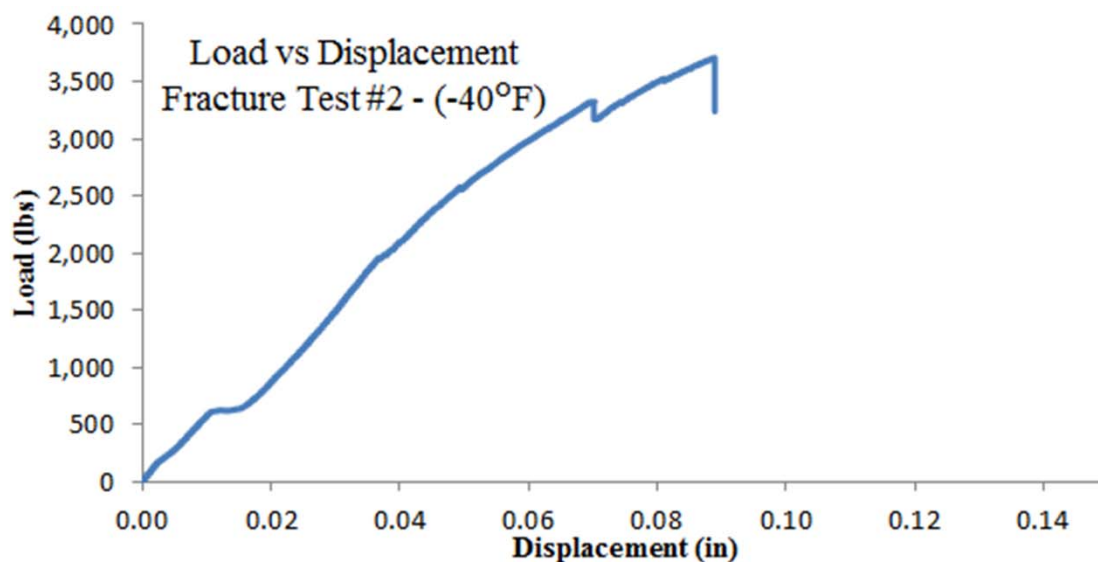
Measured Specimen Dimensions:

Diameter, D: 0.771 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-3-N40-FY09**
 Test Date: 8/13/2012
 Specimen Received: 8/6/2012
 Properties Measured: ST_z

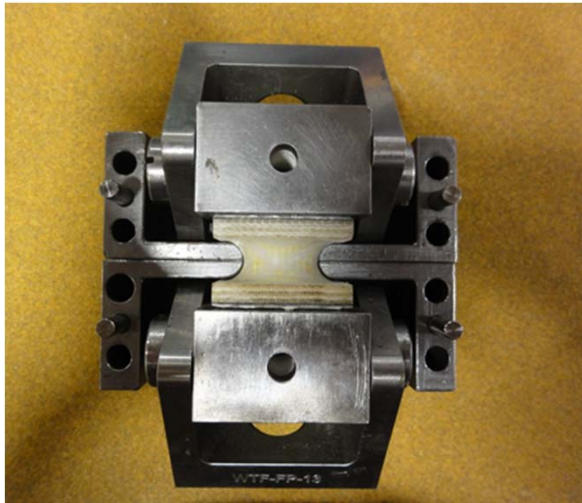
Material Properties:

Maximum Load, P_z : 3,769 lbs
 Tensile Strength, ST_z : 8,094 psi

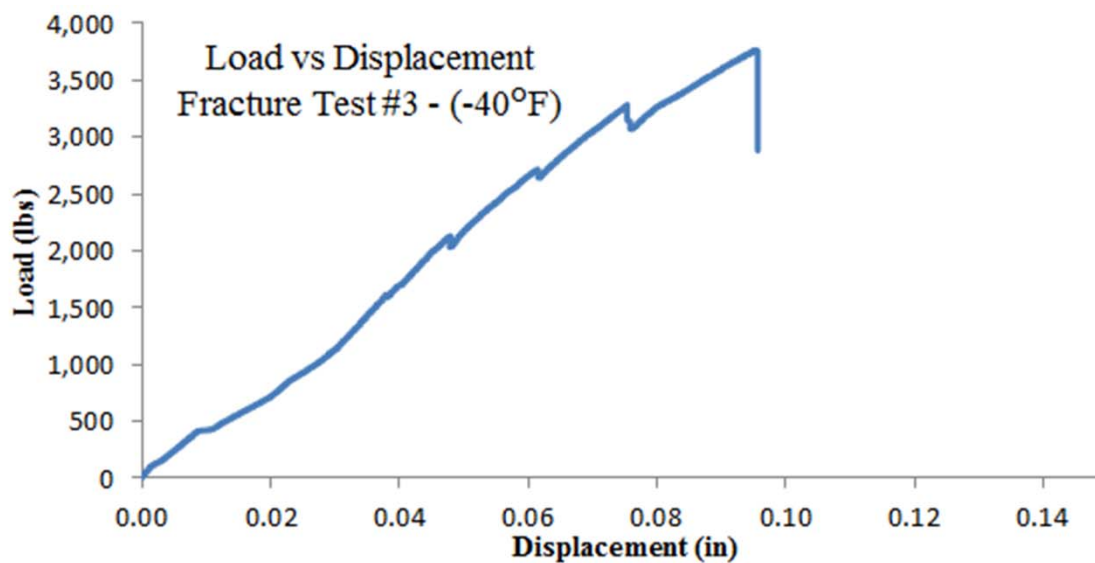
Measured Specimen Dimensions:

Diameter, D: 0.770 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)**FRACTURE TEST SUMMARY**

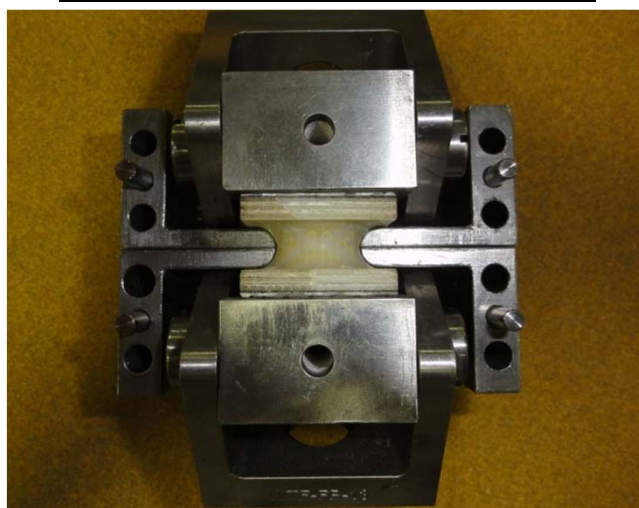
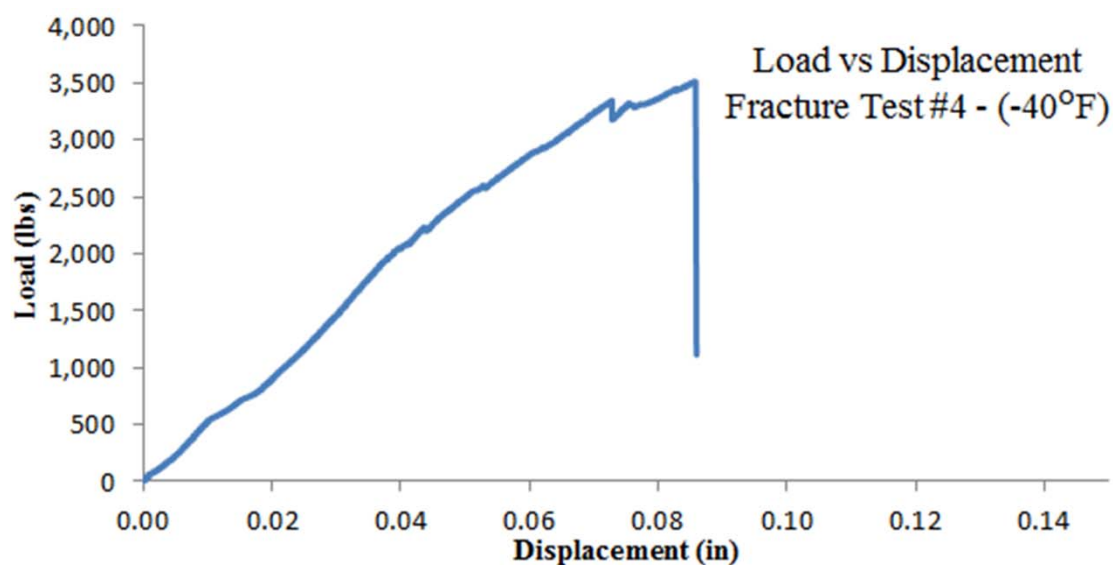
Specimen ID: **MAT3-TZF-4-N40-FY09**
Test Date: 8/14/2012
Specimen Received: 8/6/2012
Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 3,513 lbs
Tensile Strength, ST_z : 7,584 psi

Measured Specimen Dimensions:

Diameter, D: 0.768 in
Laboratory Temperature: 68°F
Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST**PICTURE OF SPECIMEN POST-TEST****Engineering Test notes:**

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-5-N40-FY09**
 Test Date: 8/14/2012
 Specimen Received: 8/6/2012
 Properties Measured: ST_z

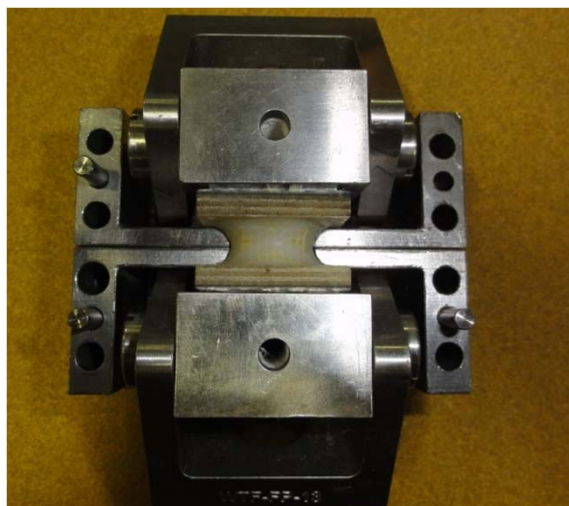
Material Properties:

Maximum Load, P_z : 3,377 lbs
 Tensile Strength, ST_z : 7,308 psi

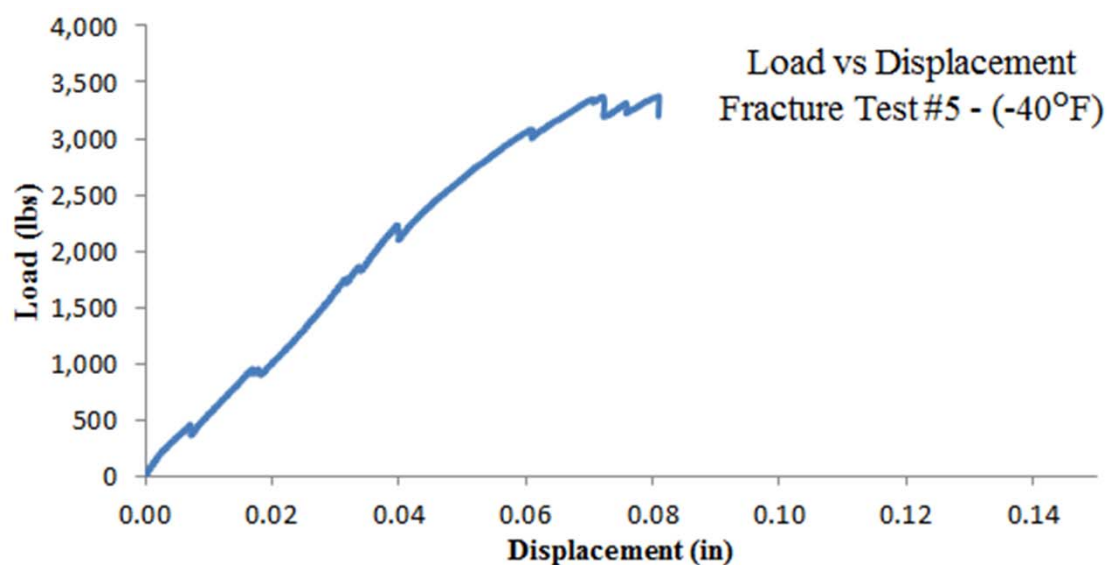
Measured Specimen Dimensions:

Diameter, D: 0.767 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 FRACTURE SPECS. OR ELASTIC SPECS.

Specimen ID Group: MAT3-TZ-70-FY09

Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber

Nominal Temperature: 70°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Tensile Strength, ST_z : 6,982 psi (Obtained with Fracture Tests)

Tensile Modulus, E_z : 1,604,104 psi (Obtained with Elastic Tests)

| ELASTIC MODULUS RESULTS | | |
|-------------------------|---------------------------|------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Modulus, E_z (psi) |
| MAT3-TZE-1-70-FY09 | 1,195 | 1,548,097 |
| MAT3-TZE-2-70-FY09 | 1,100 | 1,669,218 |
| MAT3-TZE-3-70-FY09 | 1,140 | 1,679,213 |
| MAT3-TZE-4-70-FY09 | 1,360 | 1,494,437 |
| MAT3-TZE-5-70-FY09 | 1,590 | 1,629,555 |
| Average | | 1,604,104 |

| ULTIMATE STRENGTH RESULTS | | |
|---------------------------|---------------------------|--------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) |
| MAT3-TZF-1-70-FY09 | 3,388 | 7,163 |
| MAT3-TZF-2-70-FY09 | 3,120 | 6,613 |
| MAT3-TZF-3-70-FY09 | 3,346 | 7,020 |
| MAT3-TZF-4-70-FY09 | 3,435 | 7,208 |
| MAT3-TZF-5-70-FY09 | 3,283 | 6,906 |
| Average | | 6,982 |

Test Description:

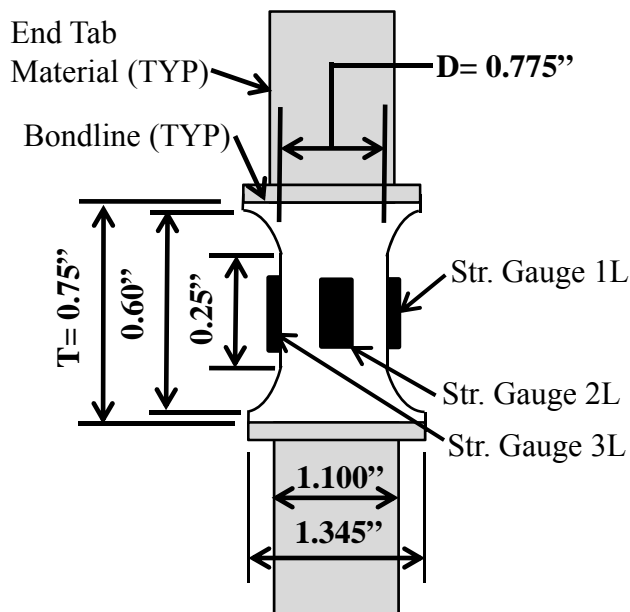
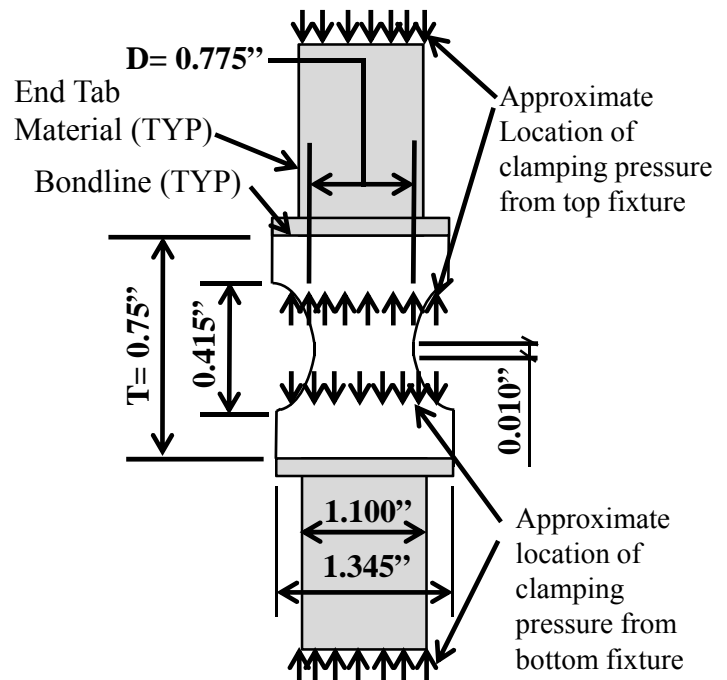
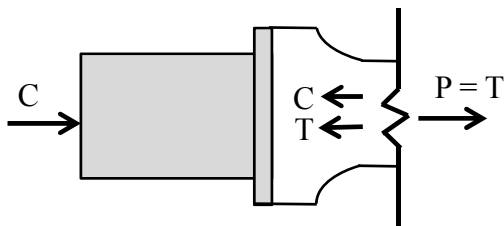
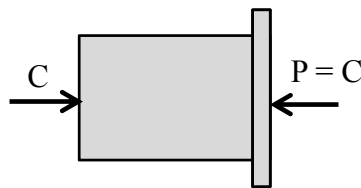
The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The glass fiber laminates are orientated along two axes known as the x and y-axes. Aramid fibers are oriented to resist tension force along the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimens consist of a cylinder with a reduced gauge section. This test is performed on the Instron 8502A. A universal joint is attached above and below the specimen to allow uniaxial tension.

The material properties are tested using two groups of specimens for this material only. The elastic modulus is measured using the “Elastic Test”. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown on the next page. The average elastic modulus as interpreted from the three strain gauges is reported in the table above. The nomenclature to identify the specimens used to measure the elastic modulus consists of “TZE” to differentiate between the specimens used to measure the ultimate stress. These specimens could not be used to measure the ultimate strength as failures occur at the bondline.

The ultimate strength is measured using the “Fracture Test”. The specimen geometry required to ensure that fracture does not occur at the bondline is used for this test. However, the gauge length (very small, 0.01 in.) disallows the application of strain gauges. In order to further ensure that failure does not occur due to high tensile stresses at the bondline, each bondline is clamped using the fixtures (top and bottom) shown in the next sheet which creates an initial compression force on the bondline. The fixture also attaches to the test frame and applies the tension force by contact at the end of the reduced section. This is illustrated by a free body diagram of the test setup which identifies the internal forces at the bondline and the internal forces in the reduced section. The clamping force is required to ensure the fixture does not open upon tension loading and is applied by tightening the bolts that are part of the fixture. The approximate magnitude is 1600 lbs. One side of the fixture attaches to the end of the specimen and the other flares around the transition area as indicated by the location on the next sheet. More information in regards to the fixture can be found in the project final report. The nomenclature to identify the specimens used to measure the ultimate strength consists of “TZF” to differentiate between the specimens used to measure the elastic modulus. Please see diagrams and pictures of the test setup on next page for more information:

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

Elastic Test: 70°F Test ConditionFracture Test: 70°F Test ConditionElastic Test Specimen Dimensions/
Strain Gauge Configuration/Front ViewFracture Test Specimen DimensionsFree Body Diagram, Force in Test AreaFree Body Diagram, Force in Bondline

P = Internal Force
 C = Initial Compression from Clamping Force
 T = Force from Testing Machine. Introduced into specimen at the pt. where the fixture houses the base of the reduced section.

Notes:

- 1) Reference F-69 to F-73 for a summary of the specimen results for the “Elastic Tests”.
- 2) Reference F-74 to F-78 for a summary of the specimen results for the “Fracture Tests”.
- 3) All “Elastic Test” specimens fail at the bondline and all “Fracture Test” specimens fail by rupture in the reduced section.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-1-70-FY09**
 Test Date: 7/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: E_z

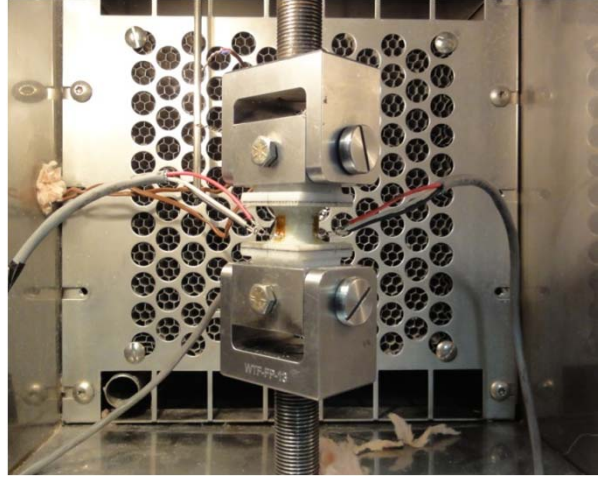
Average Material Properties:

Maximum Load, P_z : 1,195 lbs
 Tensile Modulus, E_z : 1,548,097 psi

Measured Specimen Dimensions:

Diameter, D : 0.689 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **40% Max Stress: 2,793 psi
 **10% Max Stress: 698 psi

PICTURE OF SPECIMEN PRE-TEST



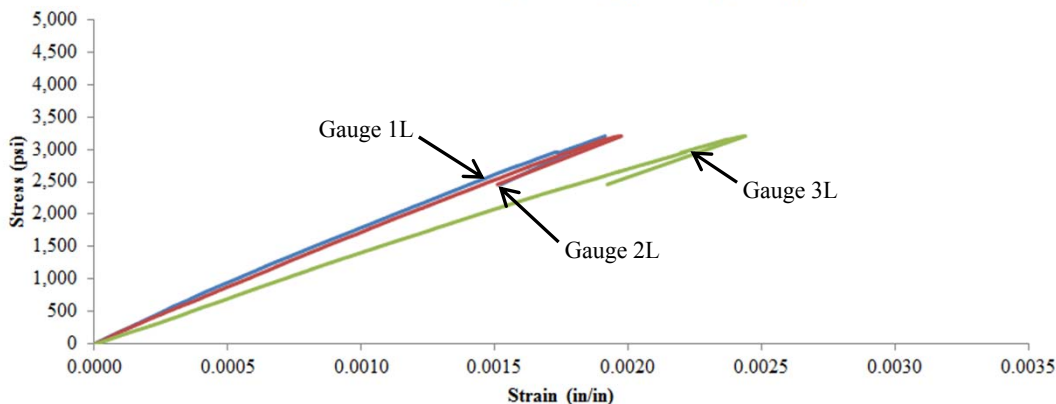
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 40% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001617 | 0.000361 | 1,667,272 |
| 2L | 0.001664 | 0.000394 | 1,649,385 |
| 3L | 0.002076 | 0.000498 | 1,327,633 |
| Average | | | 1,548,097 |

Stress-Strain Curve_70°F_1_(09-05)_Long



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 70 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-2-70-FY09**
 Test Date: 7/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: E_z

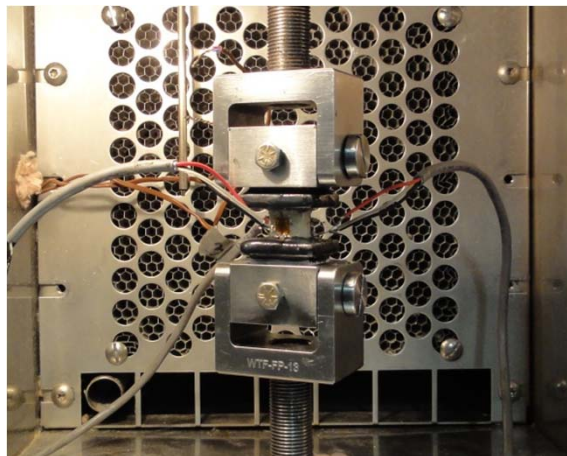
Average Material Properties:

Maximum Load, P_z : 1,100 lbs
 Tensile Modulus, E_z : 1,669,218 psi

Measured Specimen Dimensions:

Diameter, D : 0.688 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **40% Max Stress: 2,793 psi
 **10% Max Stress: 698 psi

PICTURE OF SPECIMEN PRE-TEST



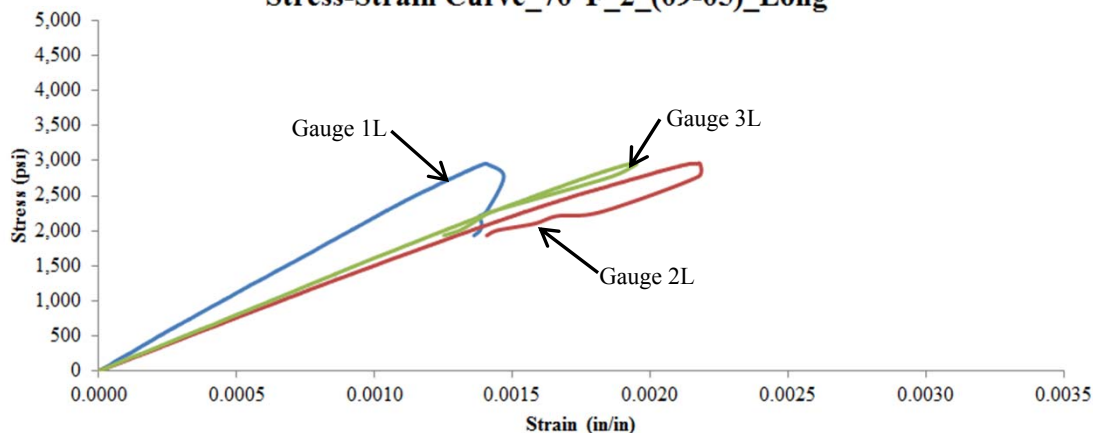
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 40% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001305 | 0.000307 | 2,099,016 |
| 2L | 0.001987 | 0.000456 | 1,367,912 |
| 3L | 0.001793 | 0.000433 | 1,540,727 |
| Average | | | 1,669,218 |

Stress-Strain Curve_70°F_2_(09-05)_Long



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 70 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-3-70-FY09**
 Test Date: 7/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: E_z

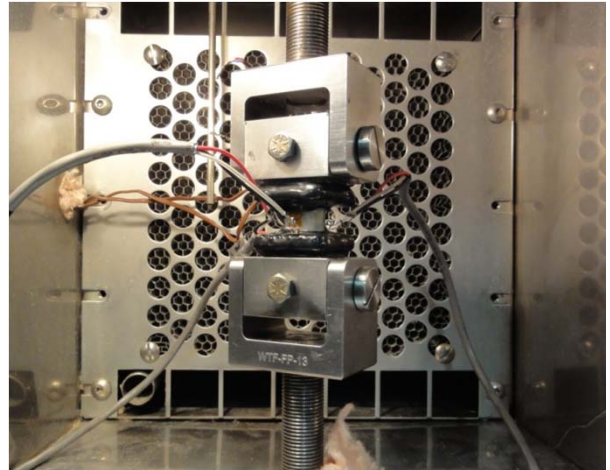
Average Material Properties:

Maximum Load, P_z : 1,140 lbs
 Tensile Modulus, E_z : 1,679,213 psi

Measured Specimen Dimensions:

Diameter, D: 0.694 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **40% Max Stress: 2,793 psi
 **10% Max Stress: 698 psi

PICTURE OF SPECIMEN PRE-TEST



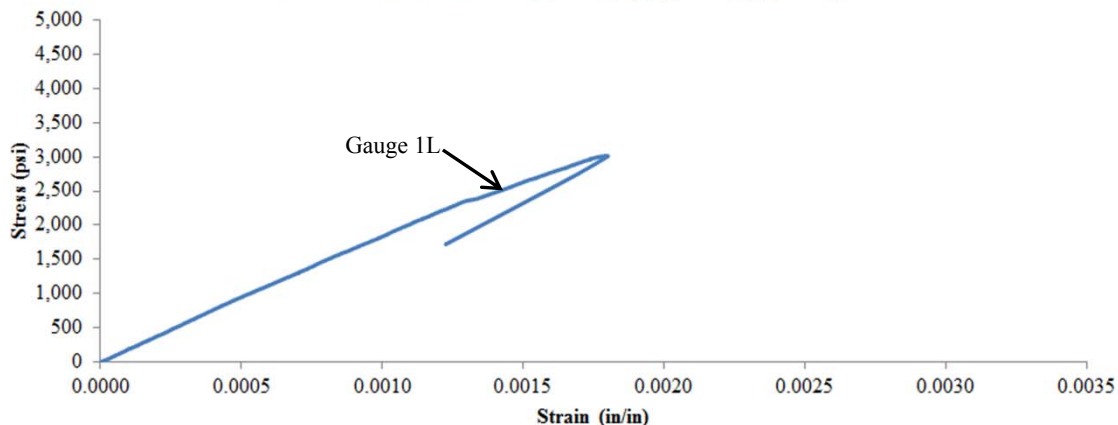
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 10% Max Stress ϵ , (in/in) | Strain @ 40% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001613 | 0.000365 | 1,679,213 |
| 2L | Lost Gauge | | |
| 3L | Lost Gauge | | |
| Average | | | 1,679,213 |

Stress-Strain Curve_70°F_3_(09-05)_Long



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 70 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-4-70-FY09**
 Test Date: 7/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: E_z

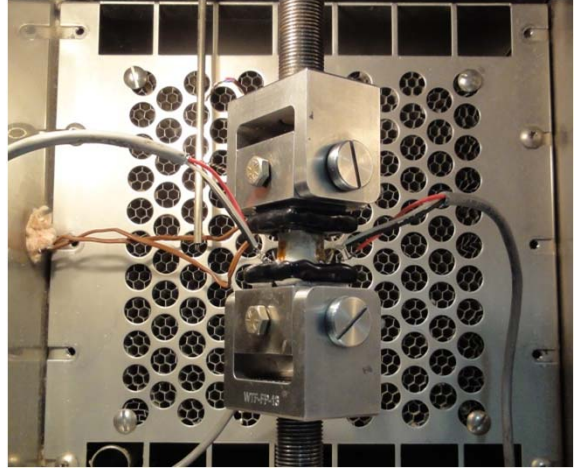
Average Material Properties:

Maximum Load, P_z : 1,360 lbs
 Tensile Modulus, E_z : 1,494,437 psi

Measured Specimen Dimensions:

Diameter, D : 0.690 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **40% Max Stress: 2,793 psi
 **10% Max Stress: 698 psi

PICTURE OF SPECIMEN PRE-TEST



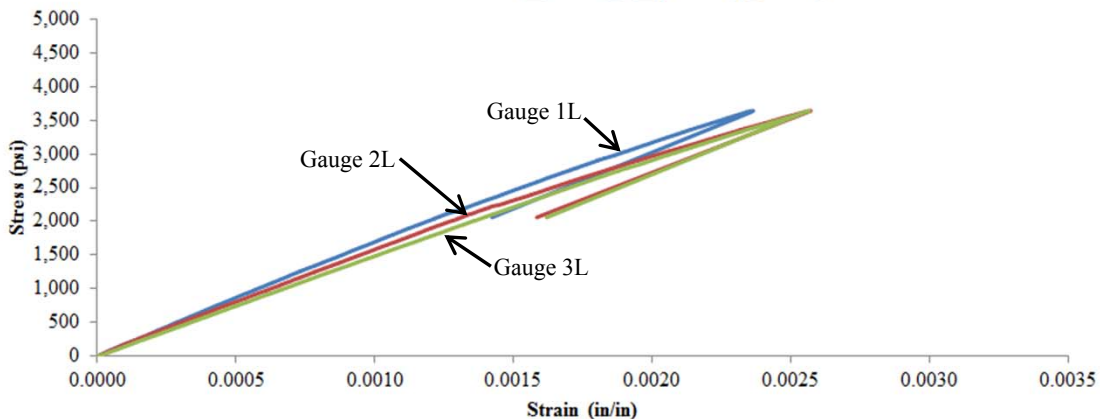
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 40% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001729 | 0.000399 | 1,574,350 |
| 2L | 0.001863 | 0.000428 | 1,458,992 |
| 3L | 0.001913 | 0.000468 | 1,449,970 |
| Average | | | 1,494,437 |

Stress-Strain Curve_70°F_4_(09-05)_Long



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 70 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-5-70-FY09**
 Test Date: 7/30/2012
 Specimen Received: 10/31/2011
 Properties Measured: E_z

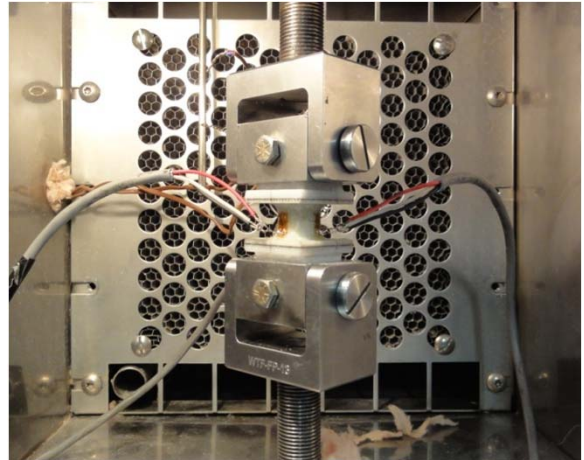
Average Material Properties:

Maximum Load, P_z : 1,590 lbs
 Tensile Modulus, E_z : 1,629,555 psi

Measured Specimen Dimensions:

Diameter, D : 0.690 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **40% Max Stress: 2,793 psi
 **10% Max Stress: 698 psi

PICTURE OF SPECIMEN PRE-TEST



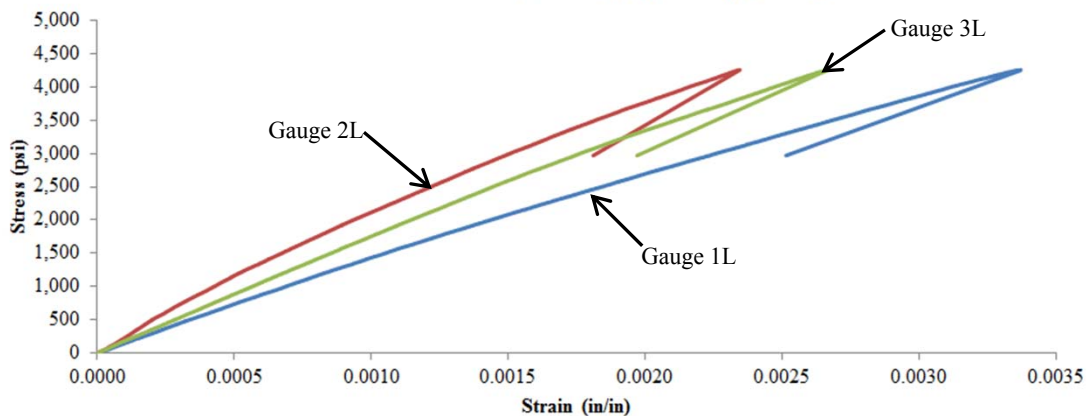
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 40% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002088 | 0.000473 | 1,296,792 |
| 2L | 0.001386 | 0.000285 | 1,901,156 |
| 3L | 0.001632 | 0.000393 | 1,690,716 |
| Average | | | 1,629,555 |

Stress-Strain Curve_70°F_5_(09-05)_Long



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 70 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 40% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)**FRACTURE TEST SUMMARY**

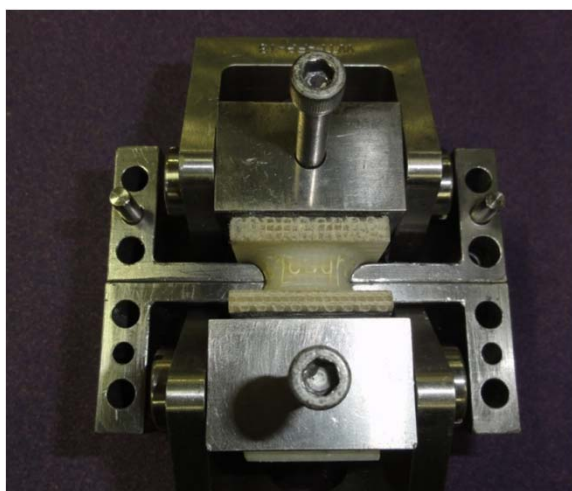
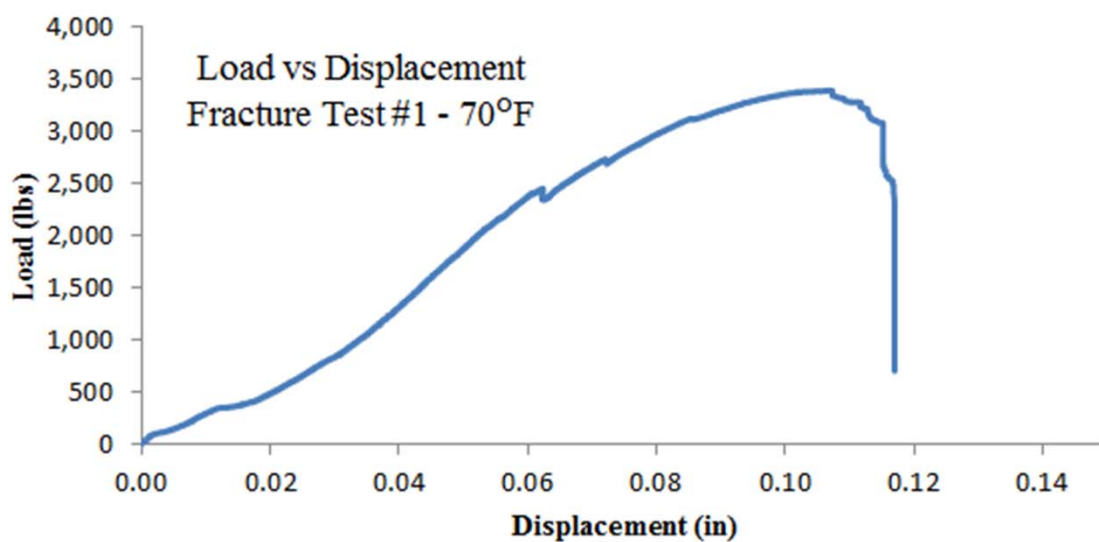
Specimen ID: **MAT3-TZF-1-70-FY09**
Test Date: 7/12/2012
Specimen Received: 10/31/2011
Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 3,388 lbs
Tensile Strength, ST_z : 7,163 psi

Measured Specimen Dimensions:

Diameter, D: 0.776 in
Laboratory Temperature: 68°F
Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST**PICTURE OF SPECIMEN POST-TEST****Engineering Test notes:**

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)**FRACTURE TEST SUMMARY**

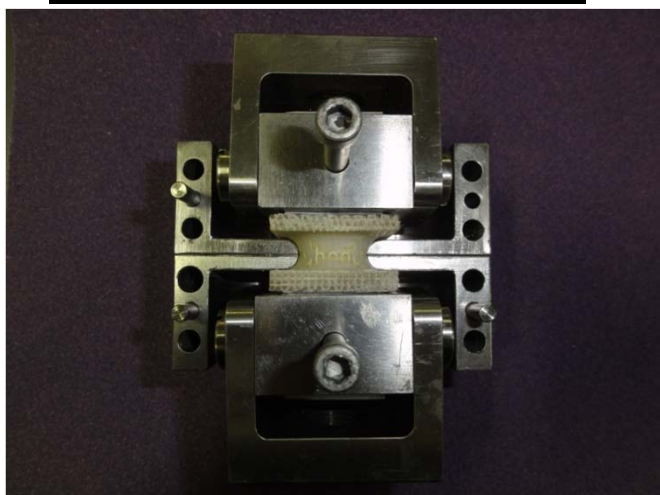
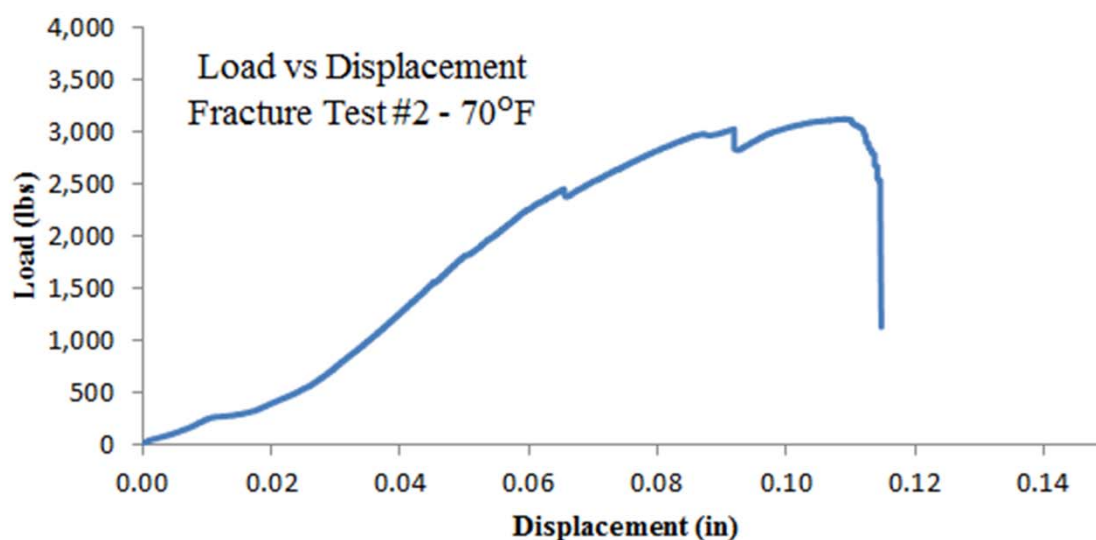
Specimen ID: **MAT3-TZF-2-70-FY09**
Test Date: 7/26/2012
Specimen Received: 10/31/2011
Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 3,120 lbs
Tensile Strength, ST_z : 6,613 psi

Measured Specimen Dimensions:

Diameter, D: 0.775 in
Laboratory Temperature: 68°F
Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST**PICTURE OF SPECIMEN POST-TEST****Engineering Test notes:**

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-3-70-FY09**
 Test Date: 7/26/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

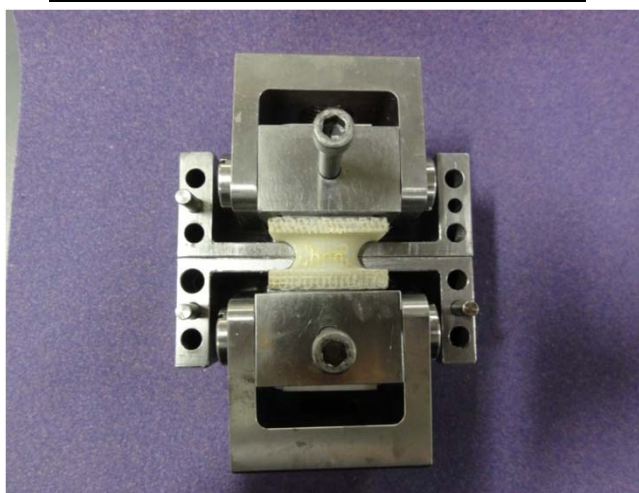
Material Properties:

Maximum Load, P_z : 3,346 lbs
 Tensile Strength, ST_z : 7,020 psi

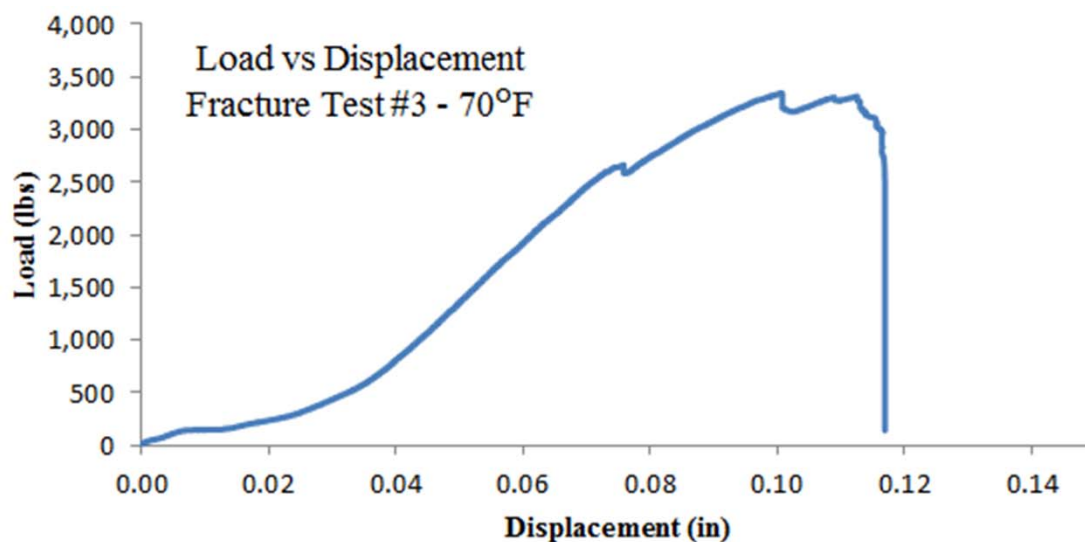
Measured Specimen Dimensions:

Diameter, D: 0.779 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)**FRACTURE TEST SUMMARY**

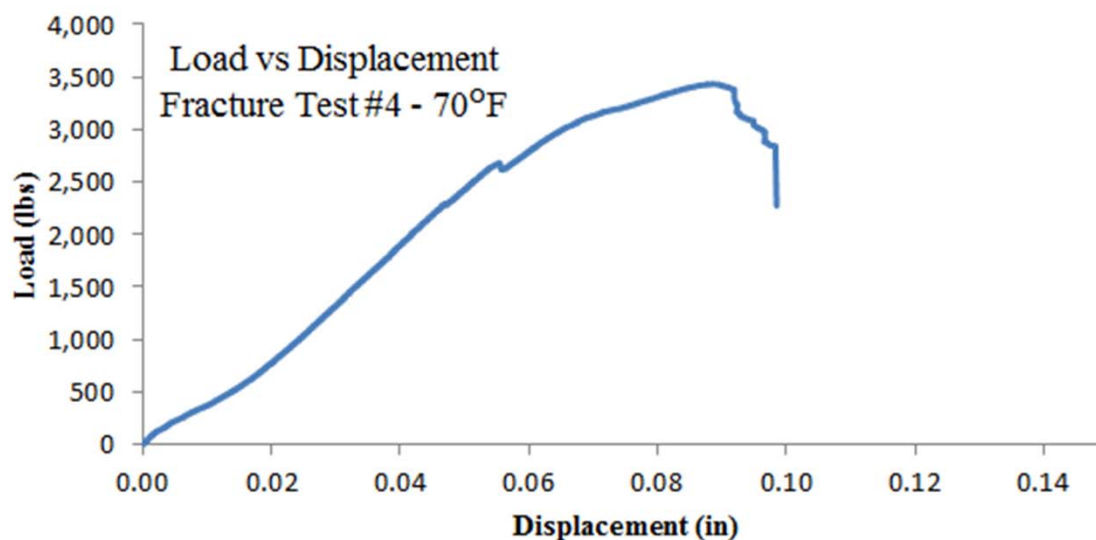
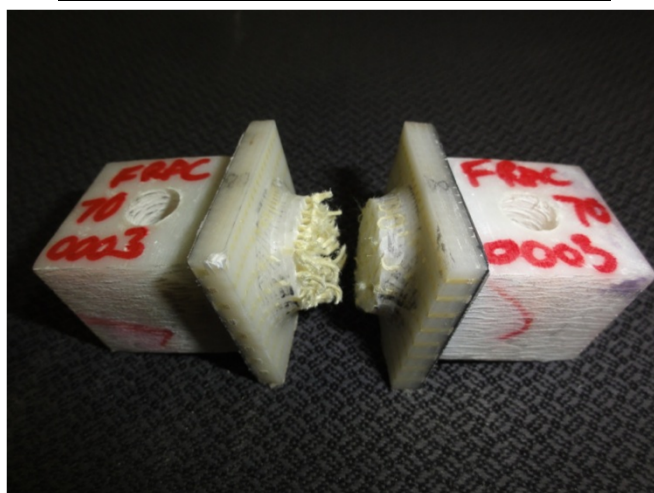
Specimen ID: **MAT3-TZF-4-70-FY09**
Test Date: 7/26/2012
Specimen Received: 10/31/2011
Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 3,435 lbs
Tensile Strength, ST_z : 7,208 psi

Measured Specimen Dimensions:

Diameter, D: 0.779 in
Laboratory Temperature: 68°F
Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST**PICTURE OF SPECIMEN POST-TEST****Engineering Test notes:**

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-5-70-FY09**
 Test Date: 7/26/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

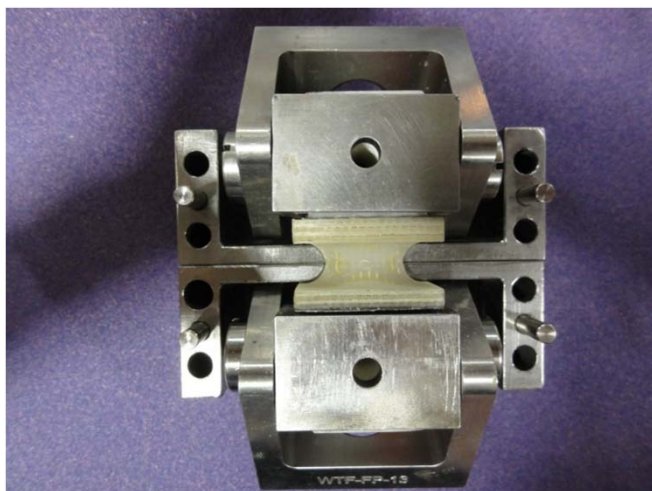
Material Properties:

Maximum Load, P_z : 3,283 lbs
 Tensile Strength, ST_z : 6,906 psi

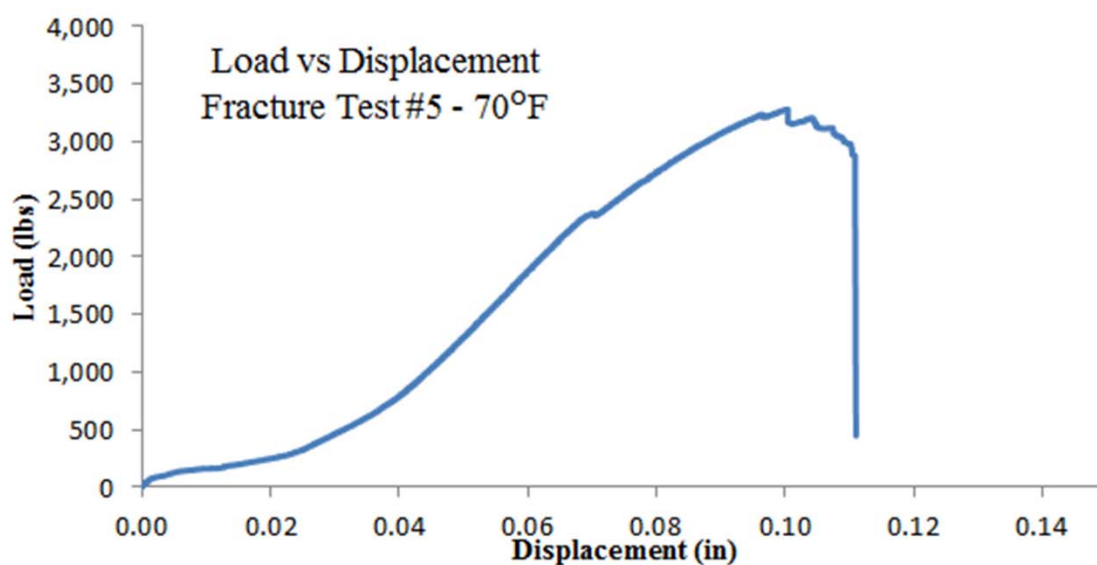
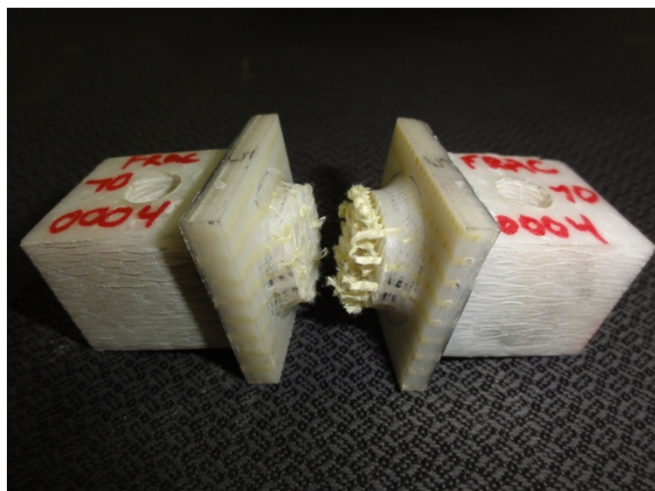
Measured Specimen Dimensions:

Diameter, D: 0.778 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 FRACTURE SPECS. OR ELASTIC SPECS.

Specimen ID Group: MAT3-TZ-140-FY09

Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber

Nominal Temperature: 140°F

Properties Measured: ST_z , E_z

Average Material Properties (5 Specimens):

Tensile Strength, ST_z : 5,373 psi (Obtained with Fracture Tests)

Tensile Modulus, E_z : 924,527 psi (Obtained with Elastic Tests)

| ELASTIC MODULUS RESULTS | | |
|-------------------------|---------------------------|------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Modulus, E_z (psi) |
| MAT3-TZE-1-140-FY09 | 1,016 | 1,122,294 |
| MAT3-TZE-2-140-FY09 | 878 | 862,452 |
| MAT3-TZE-3-140-FY09 | 736 | 918,773 |
| MAT3-TZE-4-140-FY09 | 717 | 826,316 |
| MAT3-TZE-5-140-FY09 | 736 | 892,798 |
| Average | | 924,527 |

| ULTIMATE STRENGTH RESULTS | | |
|---------------------------|---------------------------|--------------------------------|
| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) |
| MAT3-TZF-1-140-FY09 | 2,532 | 5,354 |
| MAT3-TZF-2-140-FY09 | 2,614 | 5,486 |
| MAT3-TZF-3-140-FY09 | 2,422 | 5,094 |
| MAT3-TZF-4-140-FY09 | 2,757 | 5,829 |
| MAT3-TZF-5-140-FY09 | 2,426 | 5,103 |
| Average | | 5,373 |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The glass fiber laminates are orientated along two axes known as the x and y-axes. Aramid fibers are oriented to resist tension force along the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimens consist of a cylinder with a reduced gauge section. This test is performed on the Instron 8502A. A universal joint is attached above and below the specimen to allow uniaxial tension.

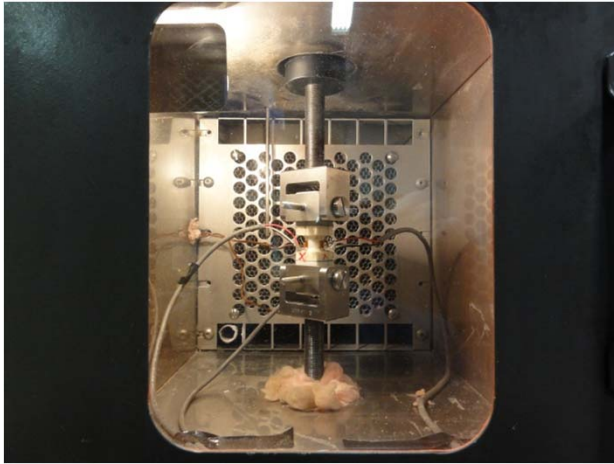
The material properties are tested using two groups of specimens for this material only. The elastic modulus is measured using the “Elastic Test”. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown on the next page. The average elastic modulus as interpreted from the three strain gauges is reported in the table above. The nomenclature to identify the specimens used to measure the elastic modulus consists of “TZE” to differentiate between the specimens used to measure the ultimate stress. These specimens could not be used to measure the ultimate strength as failures occur at the bondline.

The ultimate strength is measured using the “Fracture Test”. The specimen geometry required to ensure that fracture does not occur at the bondline is used for this test. However, the gauge length (very small, 0.01 in.) disallows the application of strain gauges. In order to further ensure that failure does not occur due to high tensile stresses at the bondline, each bondline is clamped using the fixtures (top and bottom) shown in the next sheet which creates an initial compression force on the bondline. The fixture also attaches to the test frame and applies the tension force by contact at the end of the reduced section. This is illustrated by a free body diagram of the test setup which identifies the internal forces at the bondline and the internal forces in the reduced section. The clamping force is required to ensure the fixture does not open upon tension loading and is applied by tightening the bolts that are part of the fixture. The approximate magnitude is 1600 lbs. One side of the fixture attaches to the end of the specimen and the other flares around the transition area as indicated by the location on the next sheet. More information in regards to the fixture can be found in the project final report. The nomenclature to identify the specimens used to measure the ultimate strength consists of “TZF” to differentiate between the specimens used to measure the elastic modulus. Please see diagrams and pictures of the test setup on next page for more information:

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

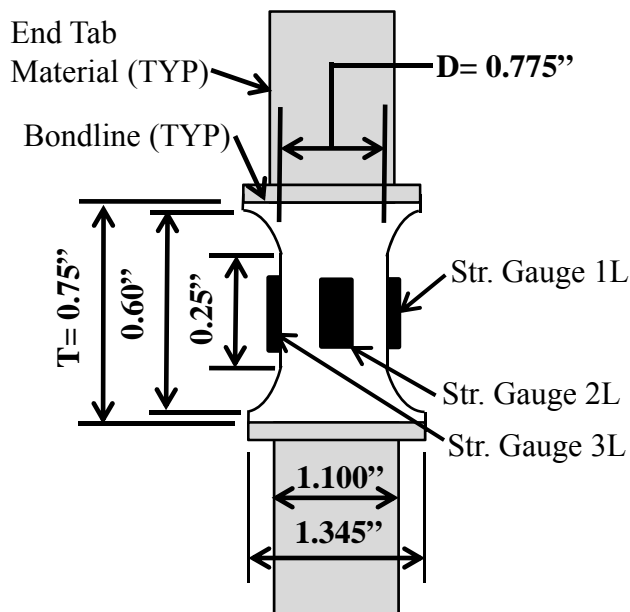
Elastic Test: 140°F Test Condition



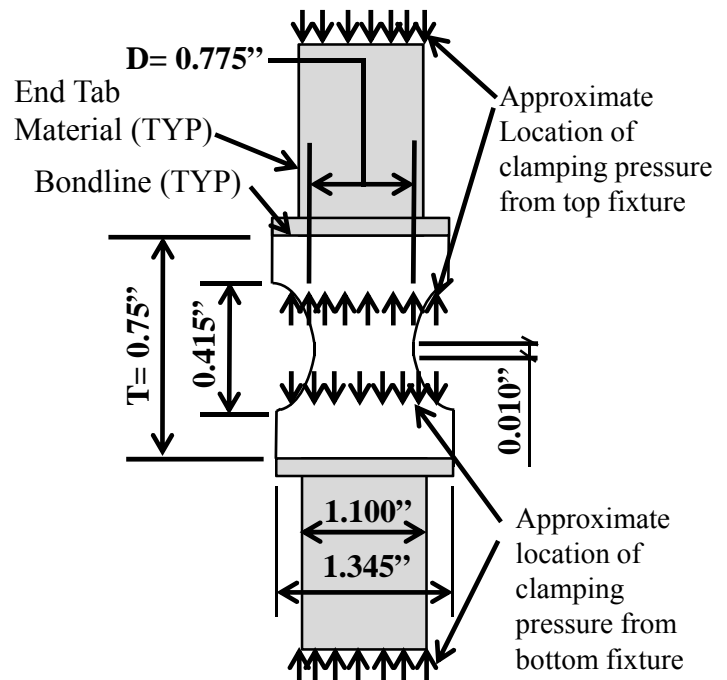
Fracture Test: 140°F Test Condition



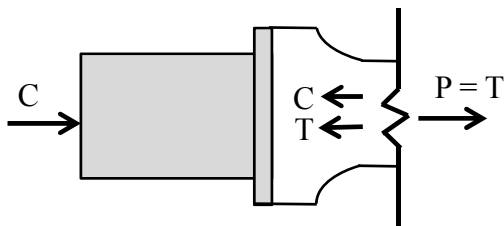
Elastic Test Specimen Dimensions/
Strain Gauge Configuration/Front View



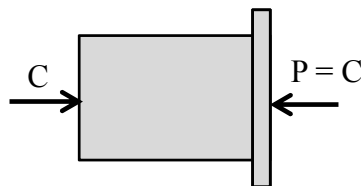
Fracture Test Specimen Dimensions



Free Body Diagram, Force in Test Area



Free Body Diagram, Force in Bondline



P = Internal Force
 C = Initial Compression from Clamping Force
 T = Force from Testing Machine. Introduced into specimen at the pt. where the fixture houses the base of the reduced section.

Notes:

- 1) Reference F-81 to F-85 for a summary of the specimen results for the “Elastic Tests”.
- 2) Reference F-86 to F-90 for a summary of the specimen results for the “Fracture Tests”.
- 3) All “Elastic Test” specimens fail at the bondline and all “Fracture Test” specimens fail by rupture in the reduced section.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-1-140-FY09**
 Test Date: 8/15/2012
 Specimen Received: 8/6/2012
 Properties Measured: E_z

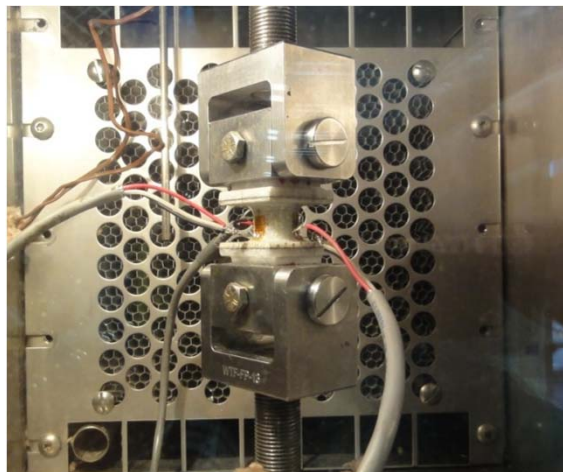
Average Material Properties:

Maximum Load, P_z : 1,016 lbs
 Tensile Modulus, E_z : 1,122,294 psi

Measured Specimen Dimensions:

Diameter, D : 0.694 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 1,881 psi
 **10% Max Stress: 537 psi

PICTURE OF SPECIMEN PRE-TEST

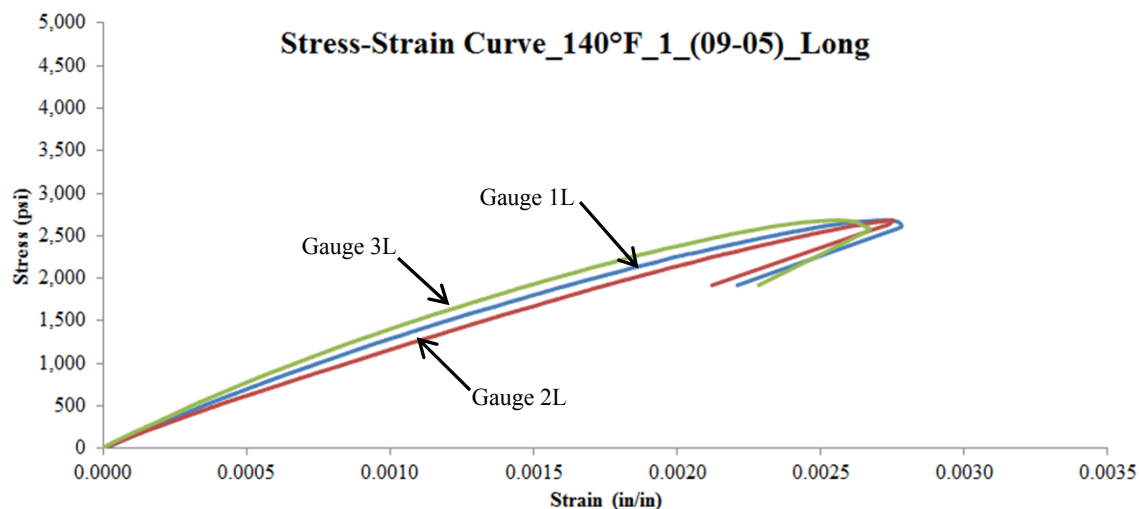


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001577 | 0.000375 | 1,116,860 |
| 2L | 0.001709 | 0.000423 | 1,044,511 |
| 3L | 0.001446 | 0.000332 | 1,205,511 |
| Average | | | 1,122,294 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 140 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-2-140-FY09**
 Test Date: 8/15/2012
 Specimen Received: 8/6/2012
 Properties Measured: E_z

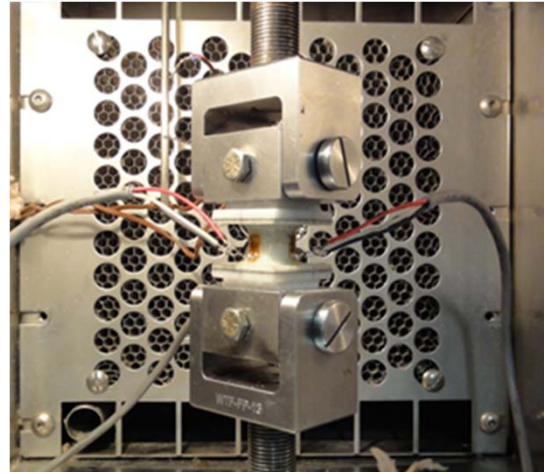
Average Material Properties:

Maximum Load, P_z : 878 lbs
 Tensile Modulus, E_z : 862,452 psi

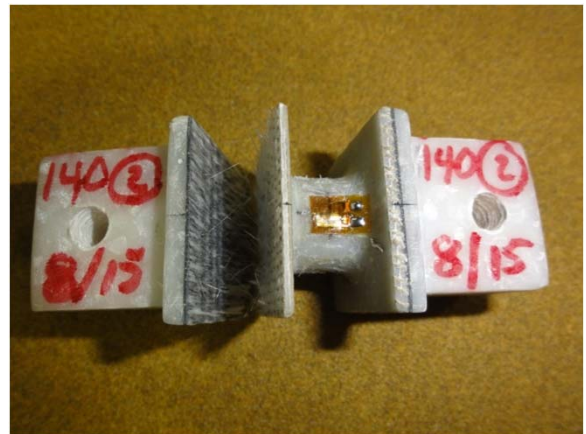
Measured Specimen Dimensions:

Diameter, D : 0.692 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 1,881 psi
 **10% Max Stress: 537 psi

PICTURE OF SPECIMEN PRE-TEST

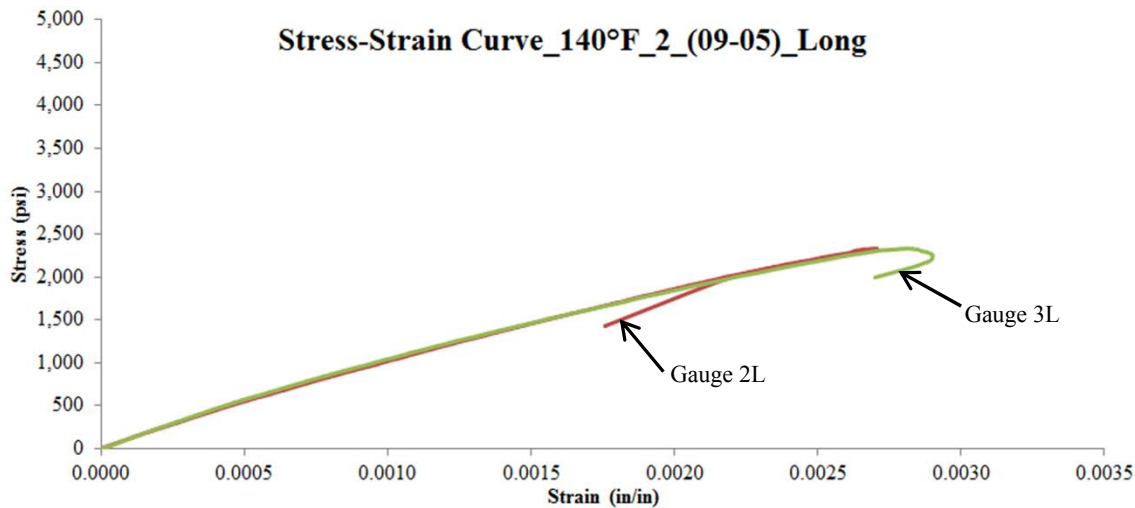


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | Lost Gauge | | |
| 2L | 0.002021 | 0.000486 | 875,188 |
| 3L | 0.002046 | 0.000465 | 849,717 |
| Average | | | 862,452 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 140 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-3-140-FY09**
 Test Date: 8/15/2012
 Specimen Received: 8/6/2012
 Properties Measured: E_z

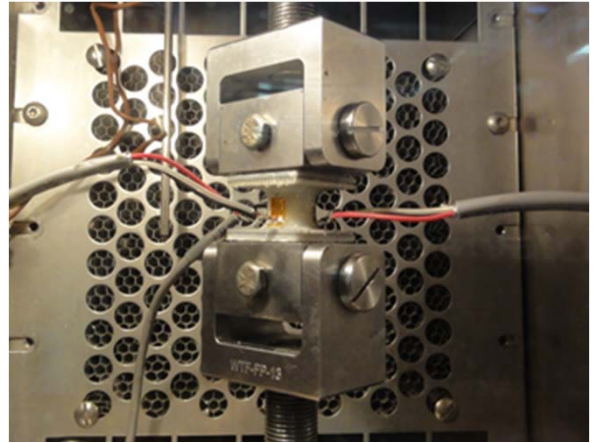
Average Material Properties:

Maximum Load, P_z : 736 lbs
 Tensile Modulus, E_z : 918,773 psi

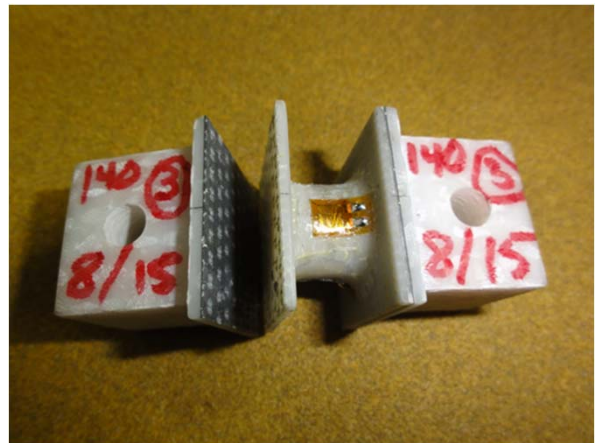
Measured Specimen Dimensions:

Diameter, D : 0.687 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 1,881 psi
 **10% Max Stress: 537 psi

PICTURE OF SPECIMEN PRE-TEST

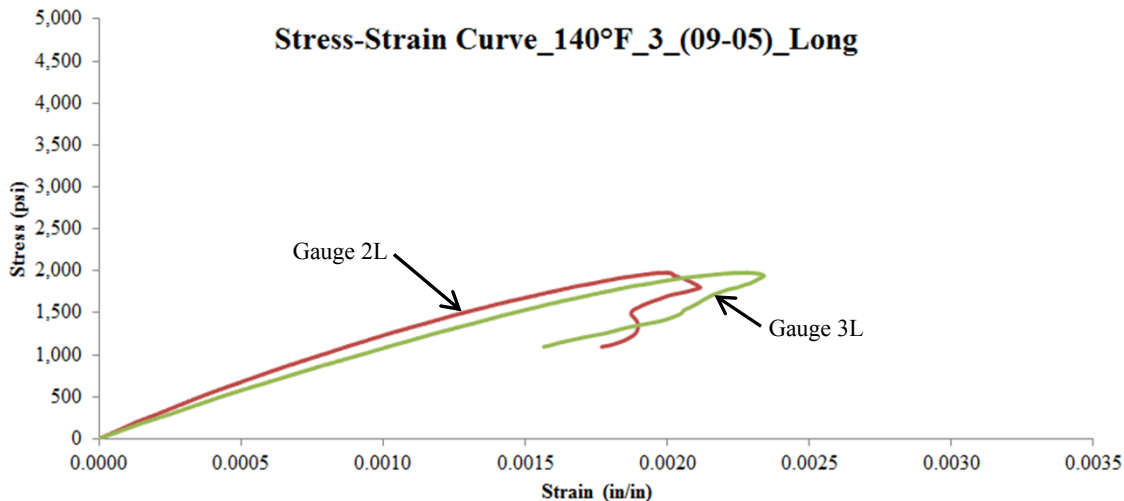


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | Lost Gauge | | |
| 2L | 0.001782 | 0.000383 | 960,443 |
| 3L | 0.001992 | 0.000460 | 877,103 |
| Average | | | 918,773 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 140 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-4-140-FY09**
 Test Date: 8/15/2012
 Specimen Received: 8/6/2012
 Properties Measured: E_z

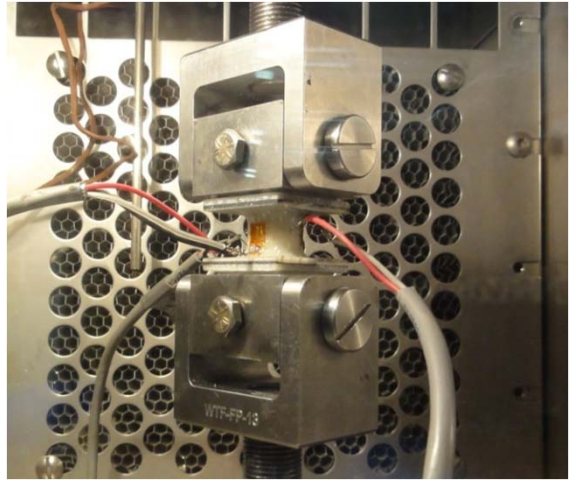
Average Material Properties:

Maximum Load, P_z : 717 lbs
 Tensile Modulus, E_z : 826,316 psi

Measured Specimen Dimensions:

Diameter, D : 0.692 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 1,881 psi
 **10% Max Stress: 537 psi

PICTURE OF SPECIMEN PRE-TEST

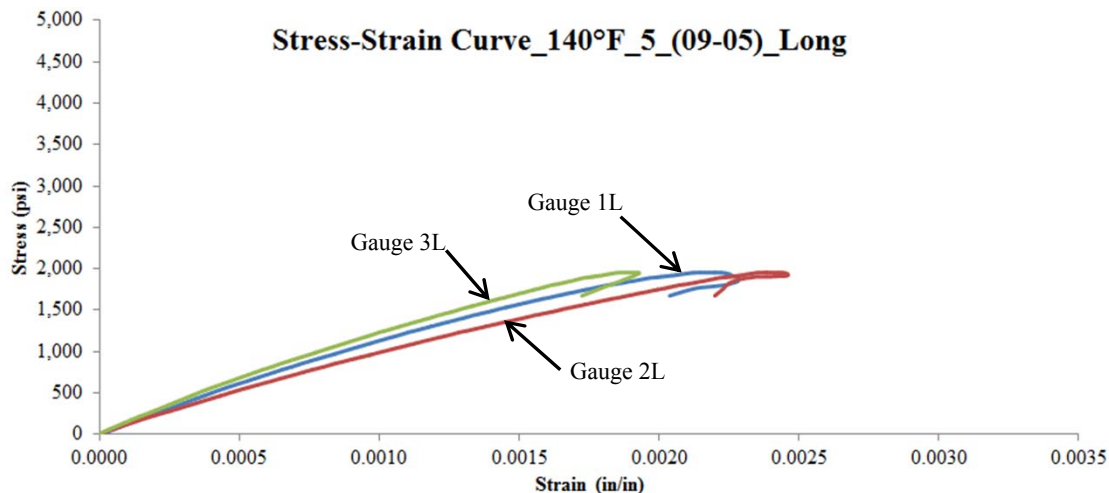


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002446 | 0.000542 | 705,406 |
| 2L | 0.002101 | 0.000428 | 802,869 |
| 3L | 0.001750 | 0.000367 | 970,674 |
| Average | | | 826,316 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 140 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

ELASTIC TEST SUMMARY

Specimen ID: **MAT3-TZE-5-140-FY09**
 Test Date: 8/16/2012
 Specimen Received: 8/6/2012
 Properties Measured: E_z

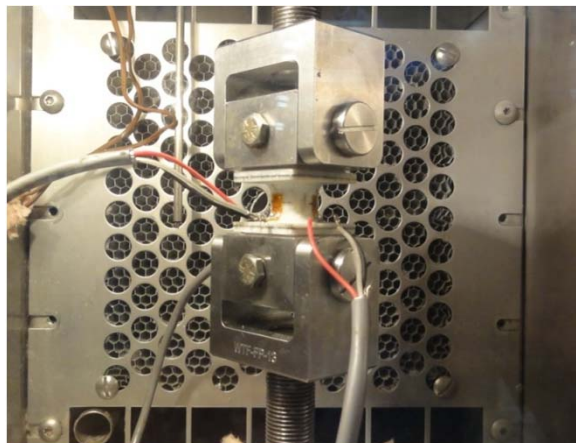
Average Material Properties:

Maximum Load, P_z : 736 lbs
 Tensile Modulus, E_z : 892,798 psi

Measured Specimen Dimensions:

Diameter, D : 0.692 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 **35% Max Stress: 1,881 psi
 **10% Max Stress: 537 psi

PICTURE OF SPECIMEN PRE-TEST

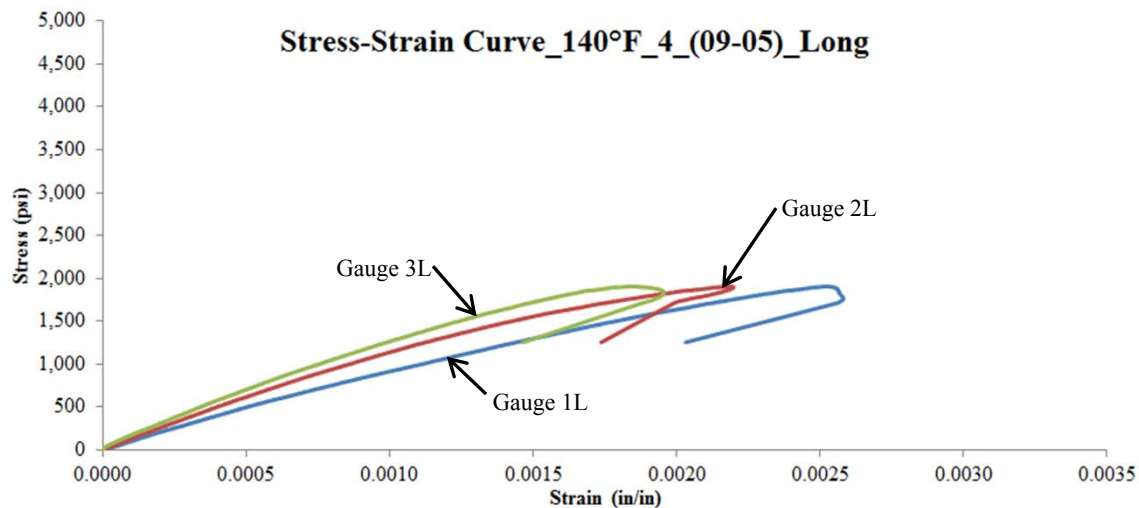


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 35% Max Stress ϵ , (in/in) | Strain @ 10% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001952 | 0.000432 | 883,545 |
| 2L | 0.002201 | 0.000503 | 790,626 |
| 3L | 0.001719 | 0.000381 | 1,004,223 |
| Average | | | 892,798 |



Engineering Test notes:

- **Maximum stress determined from the “Fracture Test” from Material 3-FY09 at 140 °F
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 10% and 35% of max stress
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-1-140-FY09**
 Test Date: 7/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

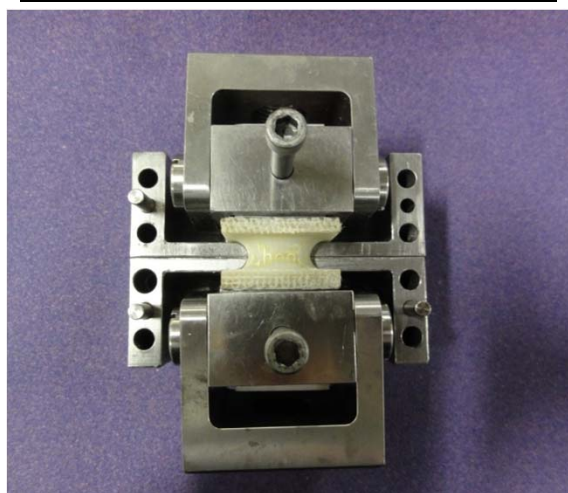
Material Properties:

Maximum Load, P_z : 2,532 lbs
 Tensile Strength, ST_z : 5,354 psi

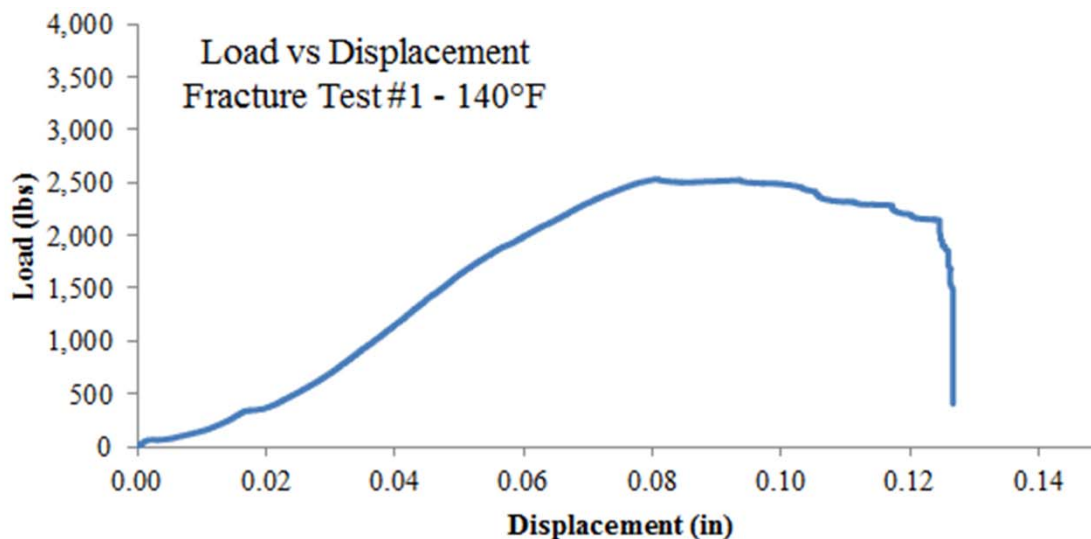
Measured Specimen Dimensions:

Diameter, D: 0.776 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-2-140-FY09**
 Test Date: 7/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

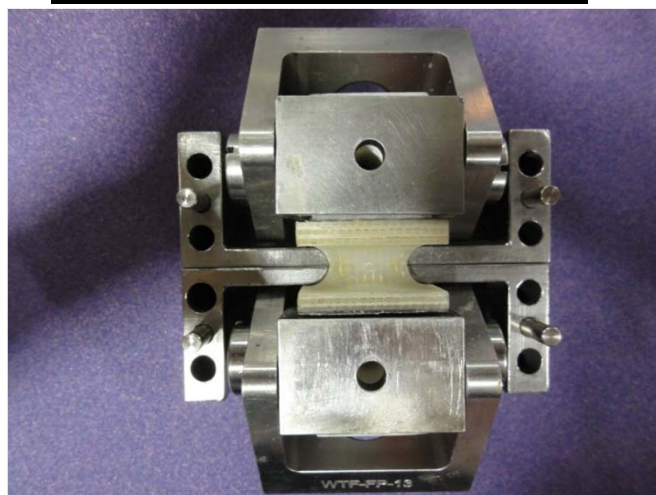
Material Properties:

Maximum Load, P_z : 2,614 lbs
 Tensile Strength, ST_z : 5,486 psi

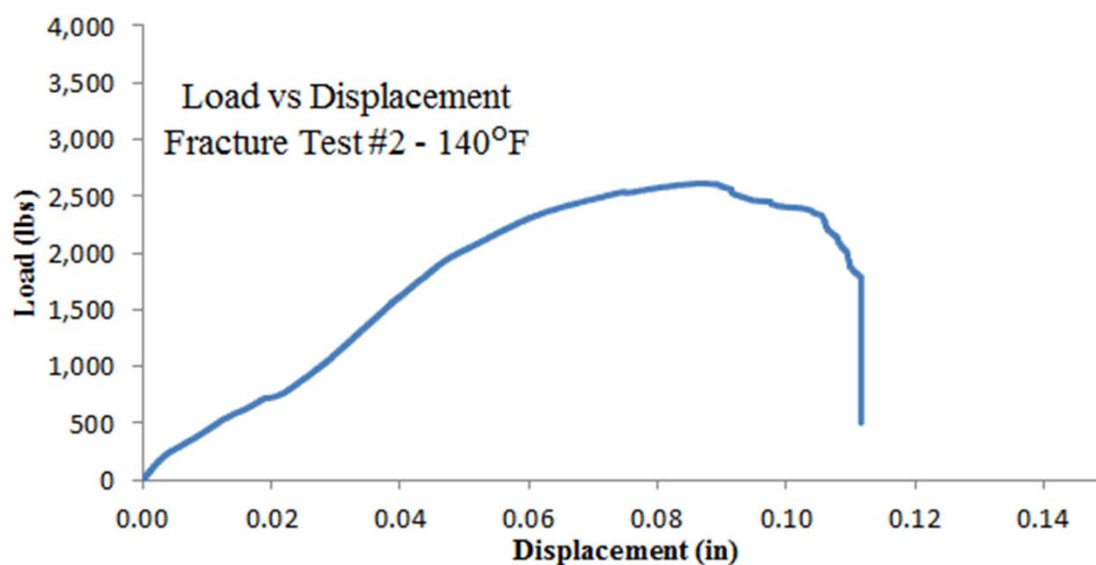
Measured Specimen Dimensions:

Diameter, D: 0.779 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-3-140-FY09**
 Test Date: 7/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 2,422 lbs
 Tensile Strength, ST_z : 5,094 psi

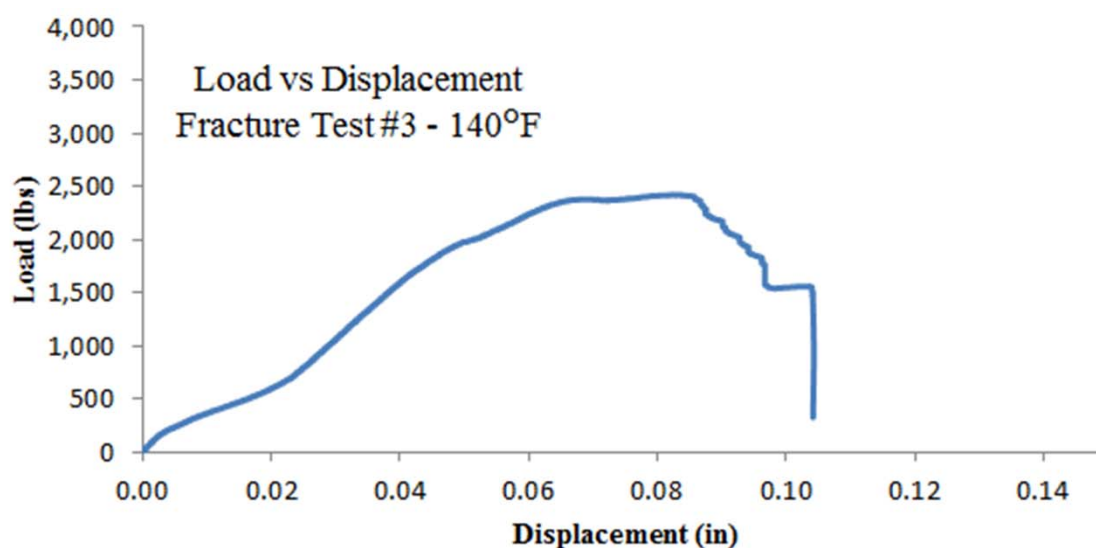
Measured Specimen Dimensions:

Diameter, D: 0.778 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-4-140-FY09**
 Test Date: 7/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

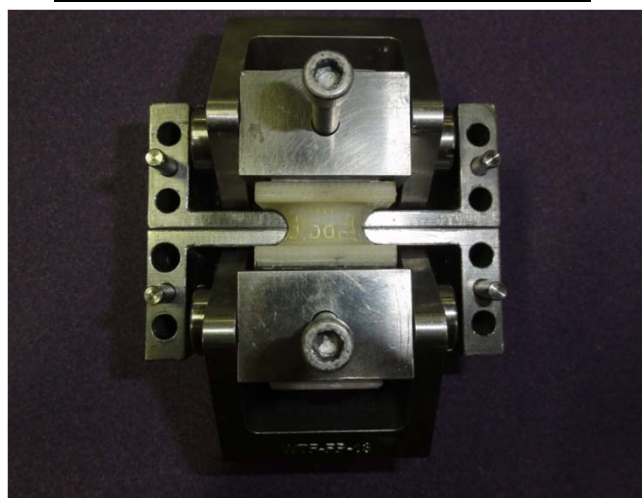
Material Properties:

Maximum Load, P_z : 2,757 lbs
 Tensile Strength, ST_z : 5,829 psi

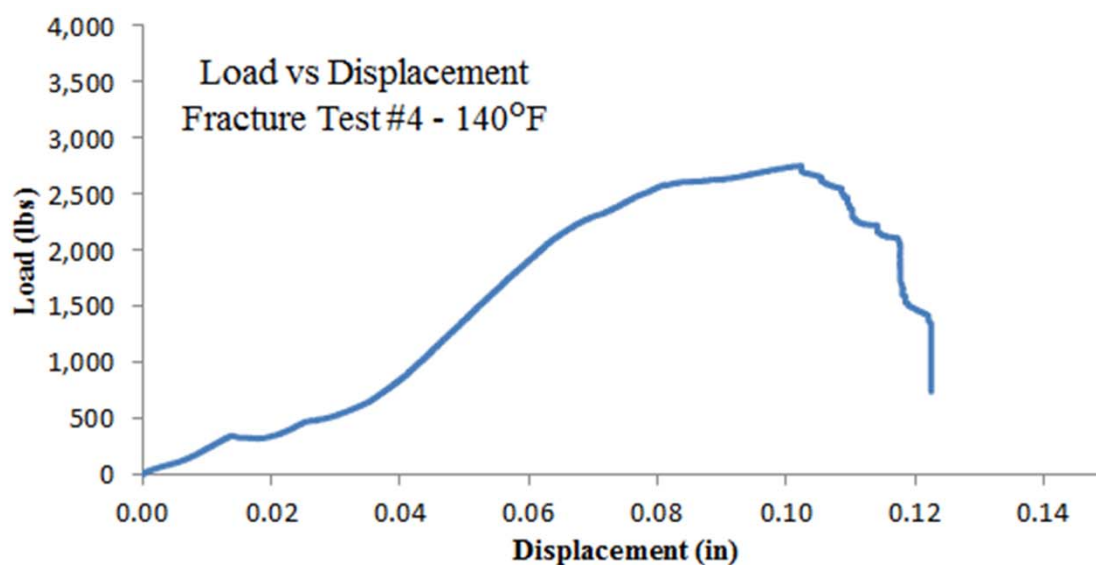
Measured Specimen Dimensions:

Diameter, D: 0.776 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

FRACTURE TEST SUMMARY

Specimen ID: **MAT3-TZF-5-140-FY09**
 Test Date: 7/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: ST_z

Material Properties:

Maximum Load, P_z : 2,426 lbs
 Tensile Strength, ST_z : 5,103 psi

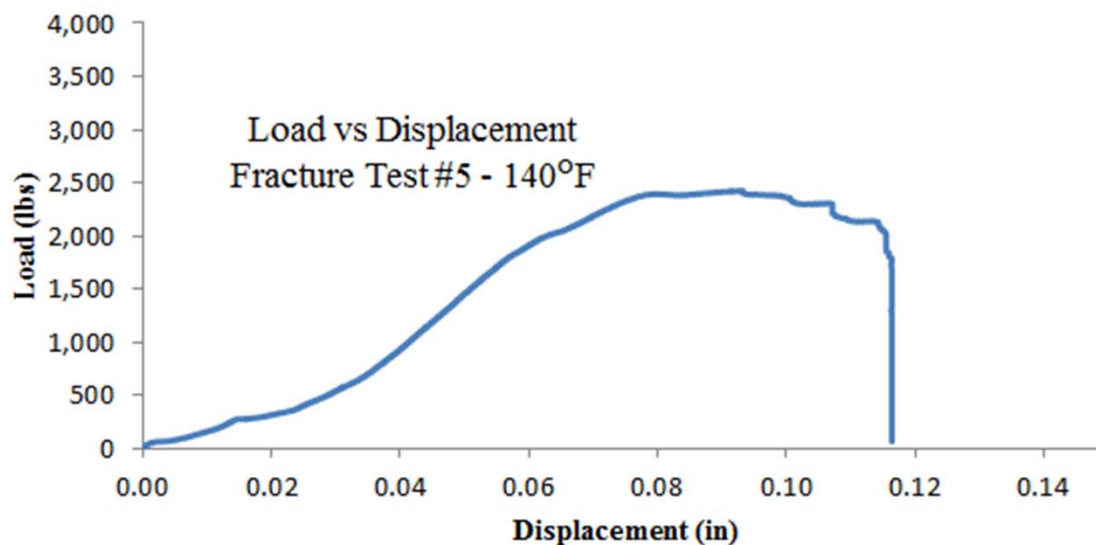
Measured Specimen Dimensions:

Diameter, D: 0.778 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Engineering Test notes:

* Fracture test Only. Load displacement curve presented

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

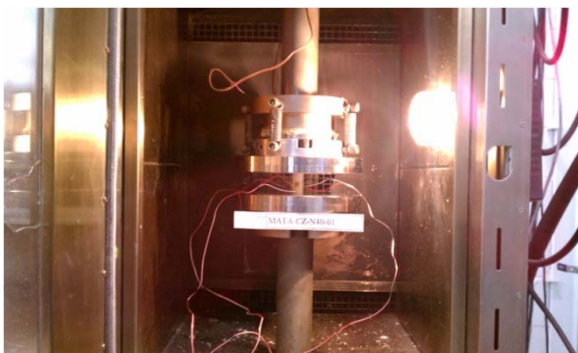
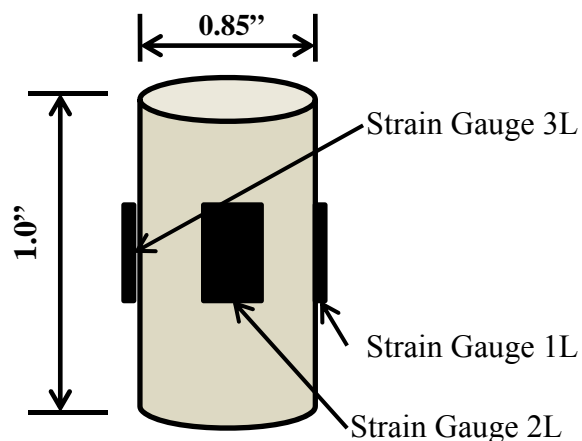
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-CZ-N40-FY09
 Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber
 Nominal Temperature: -40°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 56,134 lbs
 Compressive Strength, SC_z : 99,424 psi
 Compressive Modulus, E_z : 1,471,525 psi
 Ultimate Strain, ϵ_z : 0.070 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT3-CZ-01-N40-FY09 | 54,604 | 96,987 | 1,393,574 | 0.071 | Rupture |
| MAT3-CZ-02-N40-FY09 | 57,030 | 101,296 | 1,519,002 | 0.068 | Rupture |
| MAT3-CZ-03-N40-FY09 | 59,076 | 104,559 | 1,363,510 | 0.077 | Rupture |
| MAT3-CZ-04-N40-FY09 | 54,736 | 96,707 | 1,567,623 | 0.064 | Rupture |
| MAT3-CZ-05-N40-FY09 | 55,226 | 97,572 | 1,513,915 | 0.070 | Rupture |
| Average | 56,134 | 99,424 | 1,471,525 | 0.070 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. For this material, glass fibers are oriented in a plane which will be known as the x-y plane. Aramid fibers are oriented which resist a compressive force along the ‘z’ axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference F-92 to F-96 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-01-N40-FY09**
 Test Date: 12/7/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 54,604 lbs
 Maximum Stress, SC_z : 96,987 psi
 Compressive Modulus, E_z : 1,393,574 psi
 Ultimate Strain, ϵ_z : 0.071 in/in

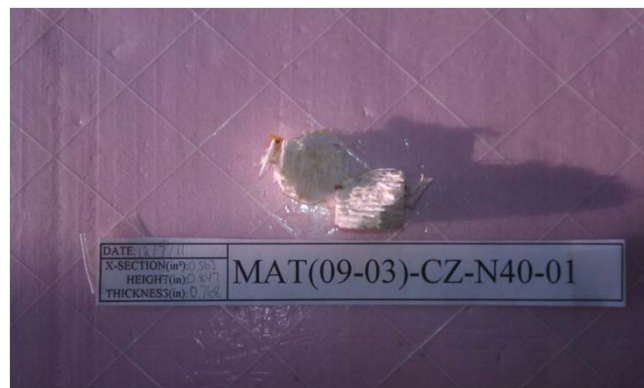
Measured Specimen Dimensions:

Length, L: 0.768 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 10,921 psi
 40% Max Load: 21,842 psi

PICTURE OF SPECIMEN PRE-TEST



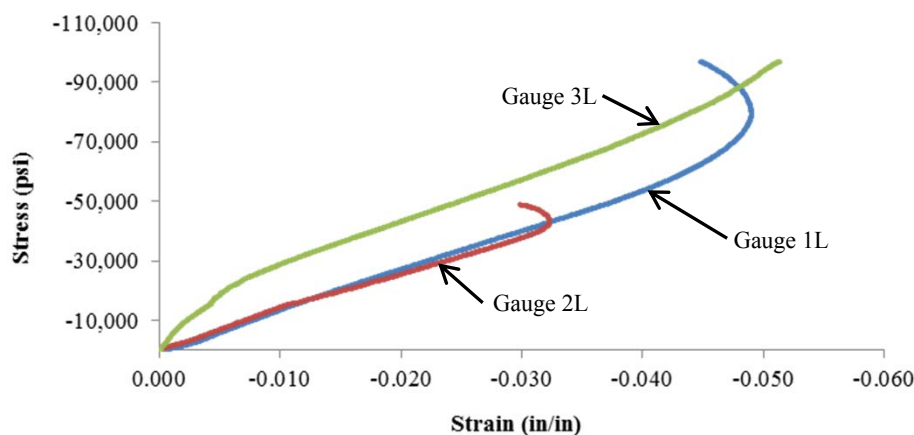
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02895 | -0.01407 | 1,304,222 |
| 2L | -0.03066 | -0.01459 | 1,207,065 |
| 3L | -0.01677 | -0.00515 | 1,669,436 |
| Average | | | 1,393,574 |

Stress-Strain Curve N40_01_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-02-N40-FY09**
 Test Date: 12/12/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 57,030 lbs
 Maximum Stress, SC_z : 101,296 psi
 Compressive Modulus, E_z : 1,519,002 psi
 Ultimate Strain, ϵ_z : 0.068 in/in

Measured Specimen Dimensions:

Length, L: 0.779 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,406 psi
 40% Max Load: 22,812 psi

PICTURE OF SPECIMEN PRE-TEST



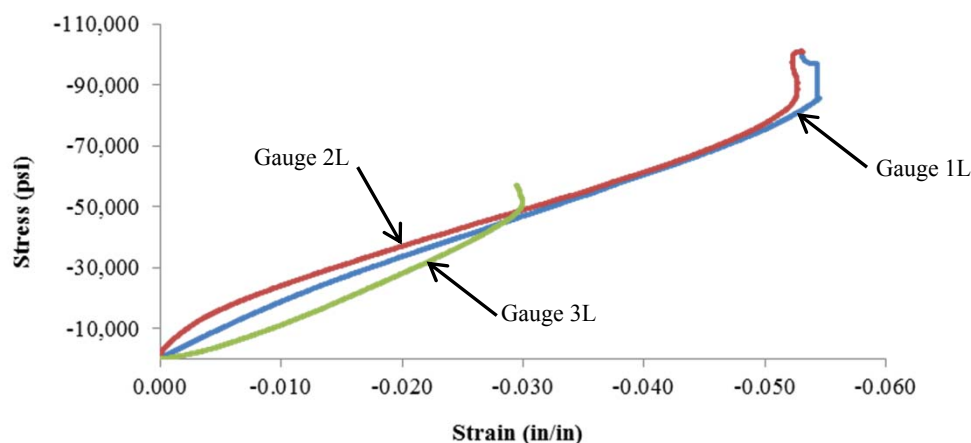
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02515 | -0.01078 | 1,409,576 |
| 2L | -0.02284 | -0.00733 | 1,306,745 |
| 3L | -0.02647 | -0.01546 | 1,840,686 |
| Average | | | 1,519,002 |

Stress-Strain Curve N40_02_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-03-N40-FY09**
 Test Date: 12/12/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 59,076 lbs
 Maximum Stress, SC_z : 104,559 psi
 Compressive Modulus, E_z : 1,363,510 psi
 Ultimate Strain, ϵ_z : 0.077 in/in

Measured Specimen Dimensions:

Length, L: 0.780 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,815 psi
 40% Max Load: 23,630 psi

PICTURE OF SPECIMEN PRE-TEST



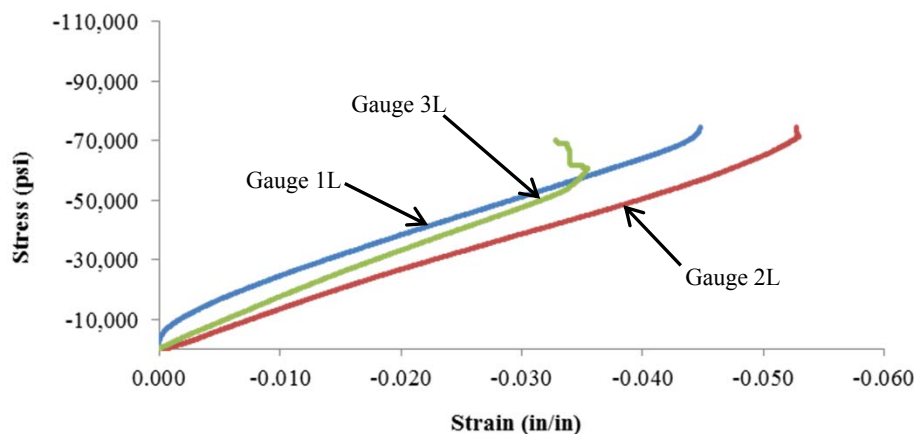
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02262 | -0.00755 | 1,388,031 |
| 2L | -0.03268 | -0.01538 | 1,208,704 |
| 3L | -0.02594 | -0.01194 | 1,493,794 |
| Average | | | 1,363,510 |

Stress-Strain Curve N40_03_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-04-N40-FY09**
 Test Date: 12/12/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 54,736 lbs
 Maximum Stress, SC_z : 96,707 psi
 Compressive Modulus, E_z : 1,567,623 psi
 Ultimate Strain, ϵ_z : 0.064 in/in

Measured Specimen Dimensions:

Length, L: 0.778 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 10,947 psi
 40% Max Load: 21,894 psi

PICTURE OF SPECIMEN PRE-TEST



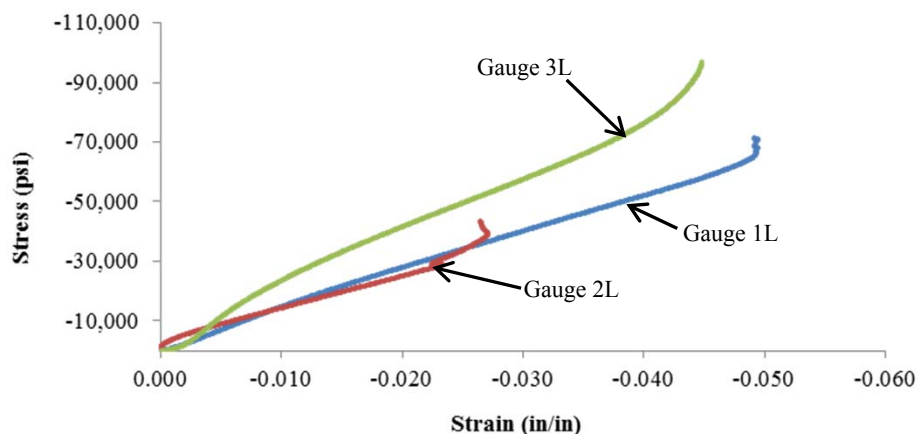
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02874 | -0.01319 | 1,243,670 |
| 2L | -0.02701 | -0.01458 | 1,555,750 |
| 3L | -0.01819 | -0.00803 | 1,903,448 |
| Average | | | 1,567,623 |

Stress-Strain Curve N40_04_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-05-N40-FY09**
 Test Date: 12/13/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 55,226 lbs
 Maximum Stress, SC_z : 97,572 psi
 Compressive Modulus, E_z : 1,513,915 psi
 Ultimate Strain, ϵ_z : 0.070 in/in

Measured Specimen Dimensions:

Length, L: 0.789 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,045 psi
 40% Max Load: 22,090 psi

PICTURE OF SPECIMEN PRE-TEST



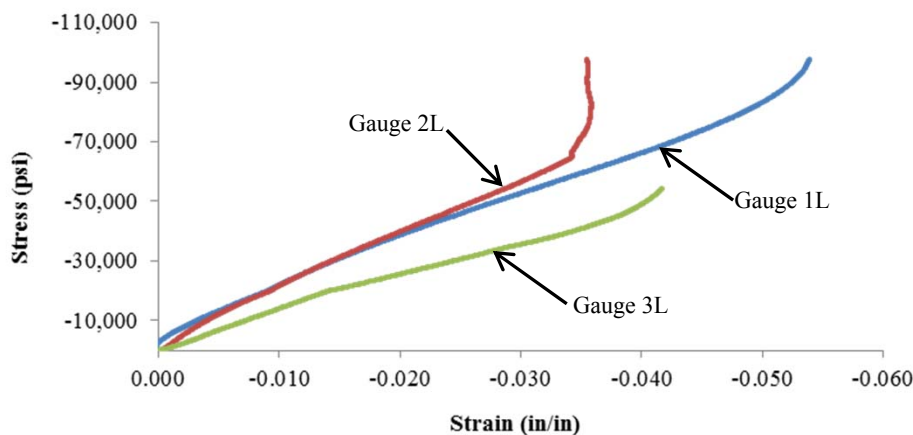
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02016 | -0.00870 | 1,702,795 |
| 2L | -0.01946 | -0.00892 | 1,850,826 |
| 3L | -0.03344 | -0.01369 | 988,123 |
| Average | | | 1,513,915 |

Stress-Strain Curve N40_05_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

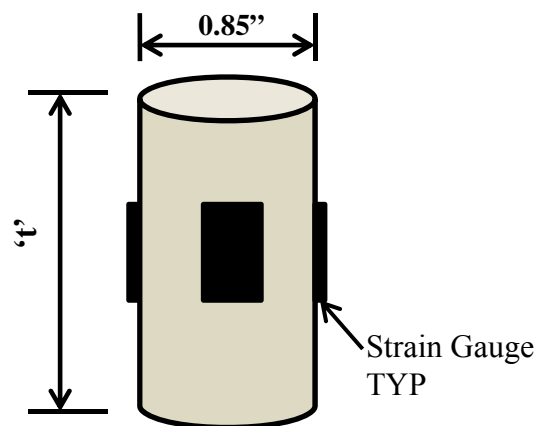
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-CZ-70-FY09**
 Material: **3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_z , E_z , ϵ_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **42,857** **lbs**
 Compressive Strength, SC_z : **75,713** **psi**
 Compressive Modulus, E_z : **1,152,591** **psi**
 Ultimate Strain, ϵ_z : **0.066** **in/in**

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT3-CZ-01-70-FY09 | 41,337 | 73,422 | 1,231,677 | 0.060 | Rupture |
| MAT3-CZ-02-70-FY09 | 45,435 | 80,131 | 1,053,985 | 0.076 | Rupture |
| MAT3-CZ-03-70-FY09 | 42,470 | 75,168 | 1,171,619 | 0.065 | Rupture |
| MAT3-CZ-04-70-FY09 | 44,263 | 77,791 | 1,166,662 | 0.067 | Rupture |
| MAT3-CZ-05-70-FY09 | 40,781 | 72,051 | 1,139,010 | 0.063 | Rupture |
| Average | 42,857 | 75,713 | 1,152,591 | 0.066 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. For this material, glass fibers are oriented in a plane which will be known as the x-y plane. Aramid fibers are oriented which resist a compressive force along the ‘z’ axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference F-98 to F-102 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-01-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 41,337 lbs
 Maximum Stress, SC_z : 73,422 psi
 Compressive Modulus, E_z : 1,231,677 psi
 Ultimate Strain, ϵ_z : 0.060 in/in

Measured Specimen Dimensions:

Length, L: 0.780 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,267 psi
 40% Max Load: 16,535 psi

PICTURE OF SPECIMEN PRE-TEST



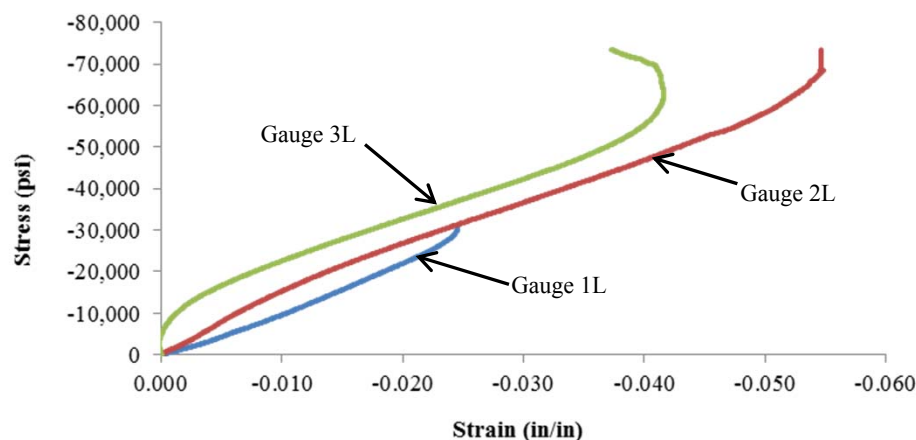
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02437 | -0.01414 | 1,436,556 |
| 2L | -0.02248 | -0.00944 | 1,126,444 |
| 3L | -0.01651 | -0.00354 | 1,132,030 |
| Average | | | 1,231,677 |

Stress-Strain Curve 70F_01_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-02-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 45,435 lbs
 Maximum Stress, SC_z : 80,131 psi
 Compressive Modulus, E_z : 1,053,985 psi
 Ultimate Strain, ϵ_z : 0.076 in/in

Measured Specimen Dimensions:

Length, L: 0.784 in
 Diameter, D: 0.850 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,087 psi
 40% Max Load: 18,174 psi

PICTURE OF SPECIMEN PRE-TEST



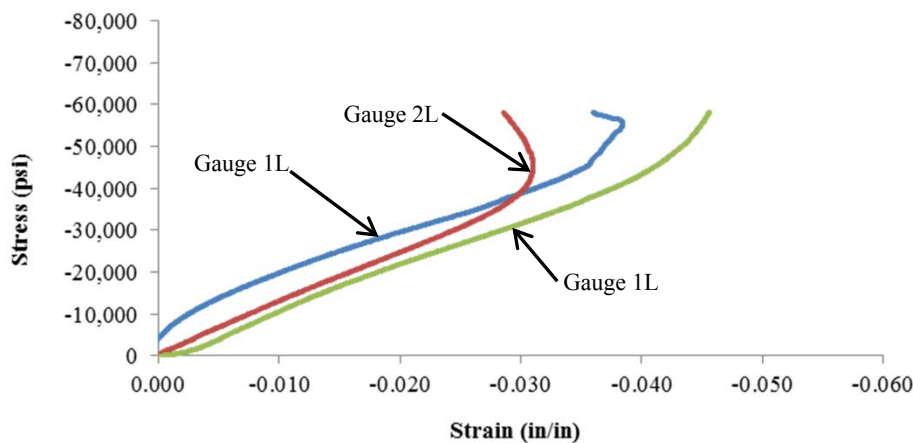
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02290 | -0.00671 | 989,580 |
| 2L | -0.02601 | -0.01236 | 1,173,872 |
| 3L | -0.03046 | -0.01441 | 998,503 |
| Average | | | 1,053,985 |

Stress-Strain Curve 70F_02_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-03-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 42,470 lbs
 Maximum Stress, SC_z : 75,168 psi
 Compressive Modulus, E_z : 1,171,619 psi
 Ultimate Strain, ϵ_z : 0.065 in/in

Measured Specimen Dimensions:

Length, L: 0.773 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,494 psi
 40% Max Load: 16,988 psi

PICTURE OF SPECIMEN PRE-TEST



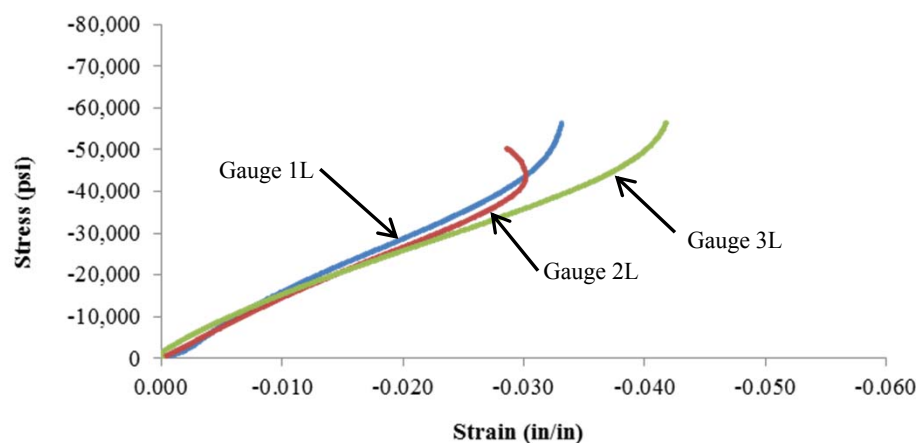
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.02107 | -0.00934 | 1,281,049 |
| 2L | -0.02288 | -0.01036 | 1,200,790 |
| 3L | -0.02427 | -0.00972 | 1,033,018 |
| Average | | | 1,171,619 |

Stress-Strain Curve 70F_03_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-04-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 44,263 lbs
 Maximum Stress, SC_z : 77,791 psi
 Compressive Modulus, E_z : 1,166,662 psi
 Ultimate Strain, ϵ_z : 0.067 in/in

Measured Specimen Dimensions:

Length, L: 0.775 in
 Diameter, D: 0.851 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,853 psi
 40% Max Load: 17,705 psi

PICTURE OF SPECIMEN PRE-TEST



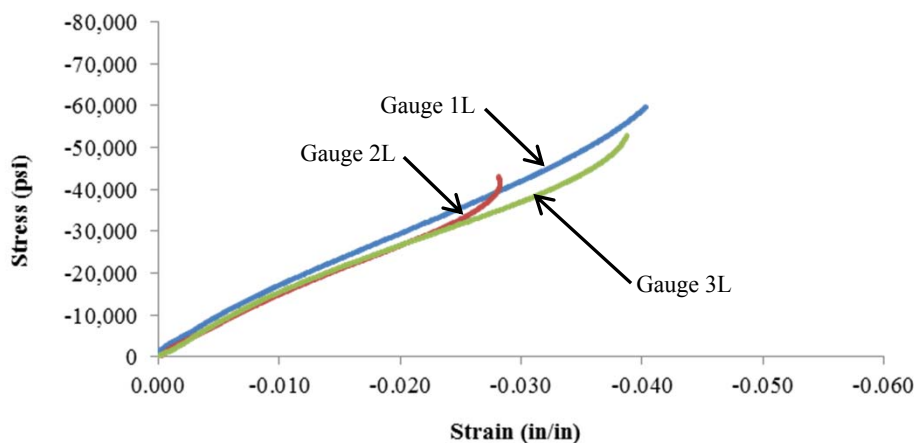
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02134 | -0.00882 | 1,242,515 |
| 2L | -0.02374 | -0.01048 | 1,173,365 |
| 3L | -0.02440 | -0.01005 | 1,084,107 |
| Average | | | 1,166,662 |

Stress-Strain Curve 70F_04_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-05-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 40,781 lbs
 Maximum Stress, SC_z : 72,051 psi
 Compressive Modulus, E_z : 1,139,010 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

Measured Specimen Dimensions:

Length, L: 0.786 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,156 psi
 40% Max Load: 16,312 psi

PICTURE OF SPECIMEN PRE-TEST



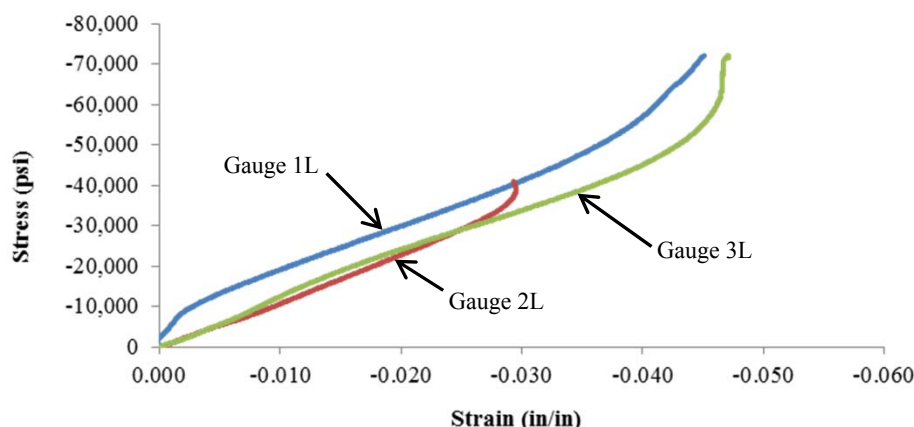
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01889 | -0.00588 | 1,107,236 |
| 2L | -0.02473 | -0.01302 | 1,230,562 |
| 3L | -0.02470 | -0.01135 | 1,079,233 |
| Average | | | 1,139,010 |

Stress-Strain Curve 70F_05_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

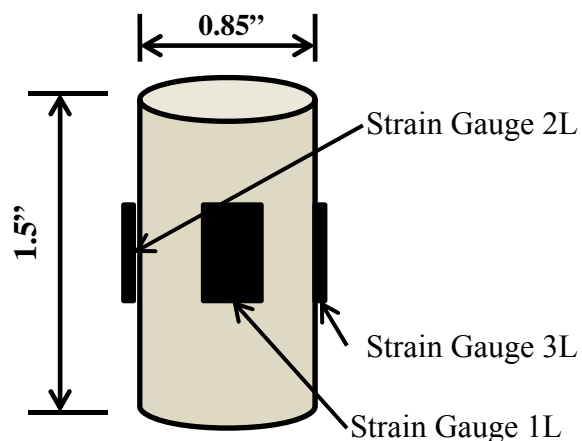
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-CZ-140-FY09
 Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 34,520 lbs
 Compressive Strength, SC_z : 61,033 psi
 Compressive Modulus, E_z : 945,082 psi
 Ultimate Strain, ϵ_z : 0.066 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT3-CZ-01-140-FY09 | 34,763 | 61,420 | 1,018,004 | 0.061 | Rupture |
| MAT3-CZ-02-140-FY09 | 35,699 | 63,072 | 959,880 | 0.066 | Rupture |
| MAT3-CZ-03-140-FY09 | 33,603 | 59,474 | 943,680 | 0.065 | Rupture |
| MAT3-CZ-04-140-FY09 | 34,224 | 60,467 | 1,034,405 | 0.059 | Rupture |
| MAT3-CZ-05-140-FY09 | 34,312 | 60,730 | 769,442 | 0.079 | Rupture |
| Average | 34,520 | 61,033 | 945,082 | 0.066 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. For this material, glass fibers are oriented in a plane which will be known as the x-y plane. Aramid fibers are oriented which resist a compressive force along the ‘z’ axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test ConditionNominal Dimensions/
Strain Gauge ConfigurationFacing ResearchersNotes:

- 1) Reference F-104 to F-108 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-01-140-FY09**
 Test Date: 12/13/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 34,763 lbs
 Maximum Stress, SC_z : 61,420 psi
 Compressive Modulus, E_z : 1,018,004 psi
 Ultimate Strain, ϵ_z : 0.061 in/in

Measured Specimen Dimensions:

Length, L: 0.774 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,953 psi
 40% Max Load: 13,905 psi

PICTURE OF SPECIMEN PRE-TEST



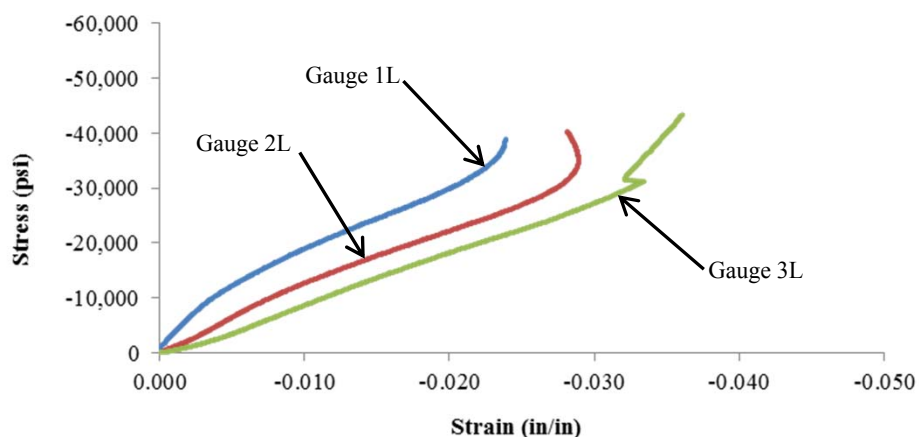
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.01509 | -0.00502 | 1,219,409 |
| 2L | -0.02257 | -0.00957 | 944,632 |
| 3L | -0.02732 | -0.01352 | 889,971 |
| Average | | | 1,018,004 |

Stress-Strain Curve 140_01_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-02-140-FY09**
 Test Date: 12/14/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 35,699 lbs
 Maximum Stress, SC_z : 63,072 psi
 Compressive Modulus, E_z : 959,880 psi
 Ultimate Strain, ϵ_z : 0.066 in/in

Measured Specimen Dimensions:

Length, L: 0.778 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,140 psi
 40% Max Load: 14,279 psi

PICTURE OF SPECIMEN PRE-TEST



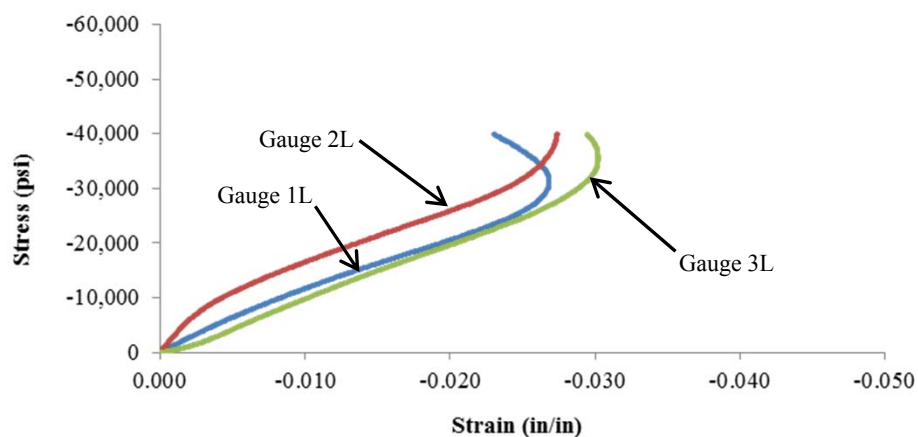
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02452 | -0.01091 | 926,261 |
| 2L | -0.01923 | -0.00628 | 974,191 |
| 3L | -0.02551 | -0.01263 | 979,190 |
| Average | | | 959,880 |

Stress-Strain Curve 140_02_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-03-140-FY09**
 Test Date: 12/14/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 33,603 lbs
 Maximum Stress, SC_z : 59,474 psi
 Compressive Modulus, E_z : 943,680 psi
 Ultimate Strain, ϵ_z : 0.065 in/in

Measured Specimen Dimensions:

Length, L: 0.771 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,721 psi
 40% Max Load: 13,441 psi

PICTURE OF SPECIMEN PRE-TEST



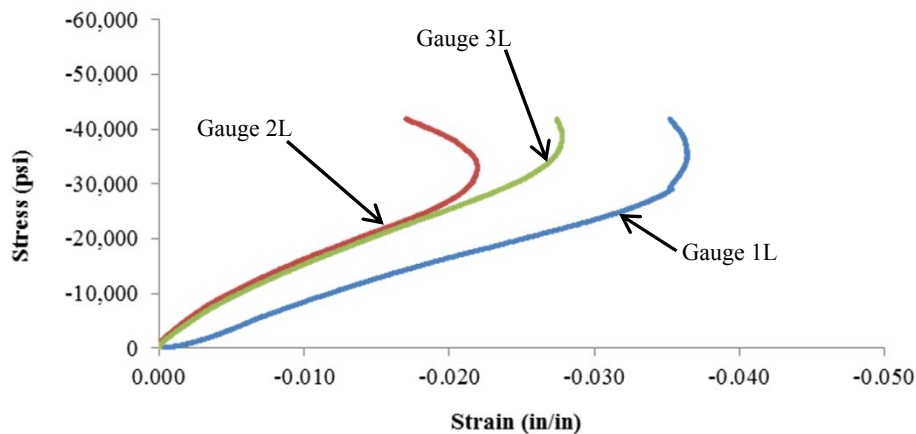
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 40% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.03039 | -0.01386 | 719,548 |
| 2L | -0.01741 | -0.00622 | 1,062,442 |
| 3L | -0.01831 | -0.00697 | 1,049,048 |
| Average | | | 943,680 |

Stress-Strain Curve 140_03_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-04-140-FY09**
 Test Date: 12/15/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 34,224 lbs
 Maximum Stress, SC_z : 60,467 psi
 Compressive Modulus, E_z : 1,034,405 psi
 Ultimate Strain, ϵ_z : 0.059 in/in

Measured Specimen Dimensions:

Length, L: 0.779 in
 Diameter, D: 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,845 psi
 40% Max Load: 13,690 psi

PICTURE OF SPECIMEN PRE-TEST



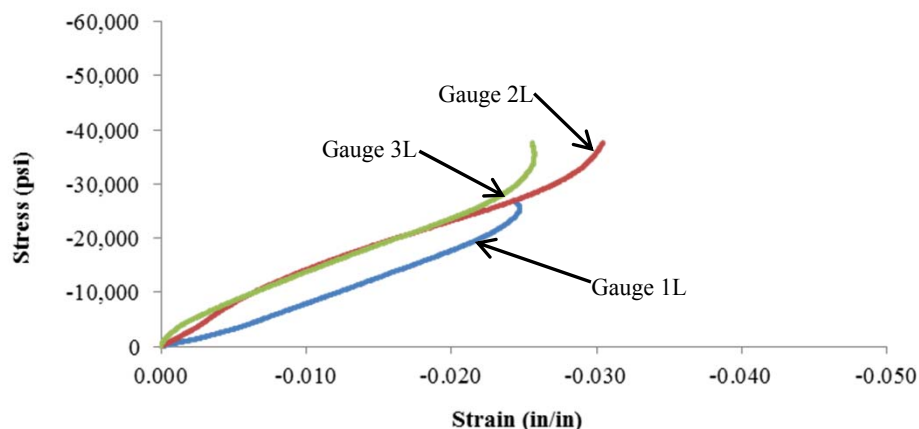
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02446 | -0.01427 | 1,186,818 |
| 2L | -0.02118 | -0.00804 | 920,749 |
| 3L | -0.02049 | -0.00835 | 995,649 |
| Average | | | 1,034,405 |

Stress-Strain Curve 140_04_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-CZ-05-140-FY09**
 Test Date: 12/15/2011
 Specimen Received: 10/31/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 34,312 lbs
 Maximum Stress, SC_z : 60,730 psi
 Compressive Modulus, E_z : 769,442 psi
 Ultimate Strain, ϵ_z : 0.079 in/in

Measured Specimen Dimensions:

Length, L: 0.775 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 6,862 psi
 40% Max Load: 13,725 psi

PICTURE OF SPECIMEN PRE-TEST



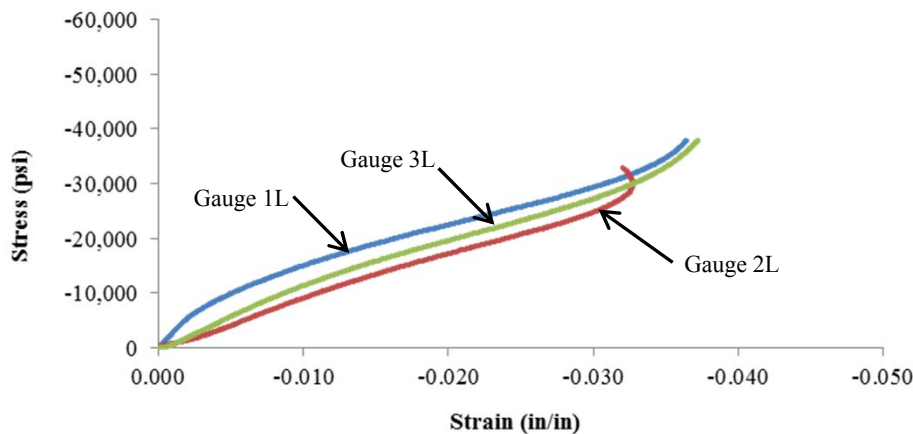
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 40% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02265 | -0.00694 | 772,921 |
| 2L | -0.02943 | -0.01335 | 755,567 |
| 3L | -0.02632 | -0.01074 | 779,837 |
| Average | | | 769,442 |

Stress-Strain Curve 140_05_(09-03)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 40% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-SXZ-N40-FY09

Material: 3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber

Nominal Temperature: -40°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 561 lbs

Shear Strength, S_{xz} : 6,373 psi

Shear Modulus, G_{xz} : 406,384 psi

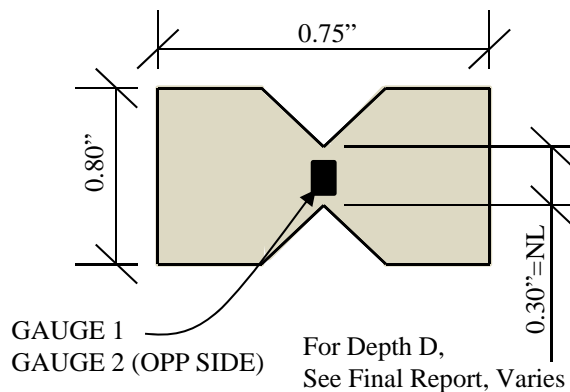
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT3-SXZ-01-N40-FY09 | 417 | 4,839 | 445,362 | Shear |
| MAT3-SXZ-02-N40-FY09 | 667 | 7,169 | 372,047 | Shear |
| MAT3-SXZ-03-N40-FY09 | 706 | 8,240 | 374,372 | Shear |
| MAT3-SXZ-04-N40-FY09 | 585 | 6,666 | 377,143 | Shear |
| MAT3-SXZ-05-N40-FY09 | 430 | 4,950 | 462,998 | Shear |
| Average | 561 | 6,373 | 406,384 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen ,at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets F-110 to F-114
- 2) Five specimens tested with results shown.
- 3) All specimens shown failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration**

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-01-N40-FY09
 Test Date: 8/24/2012
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

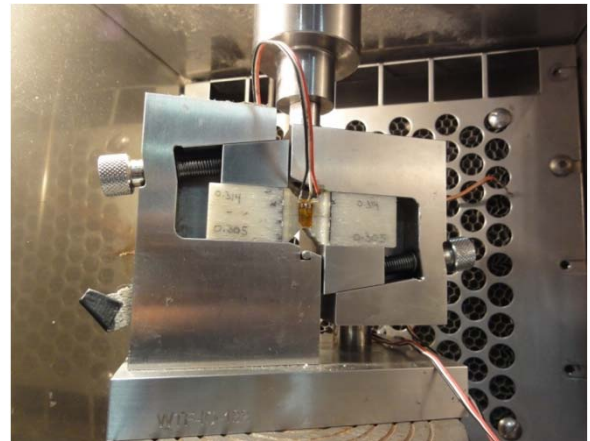
Average Material Properties:

Ultimate Load, P_{max} : 417 lbs
 Shear Strength, S_{xz} : 4,839 psi
 Shear Modulus, G_{xz} : 445,362 psi

Measured Specimen Dimensions:

Depth, D: 0.279 in
 Notch Length, NL: 0.309 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 209 lbs
 20% Max Load: 83 lbs

PICTURE OF SPECIMEN PRE-TEST

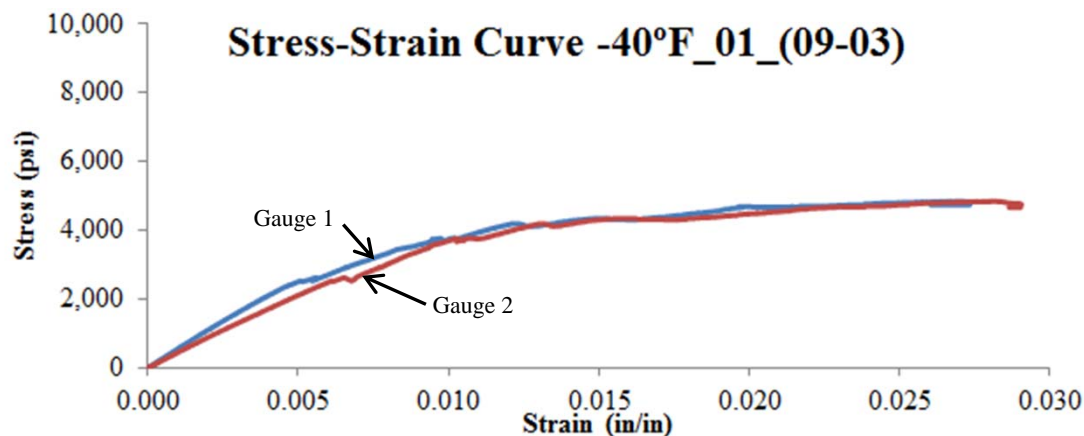


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0048 | 0.0018 | 486,524 |
| 2 | 0.0058 | 0.0022 | 404,201 |
| Average | | | 445,362 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-02-N40-FY09
 Test Date: 8/24/2012
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

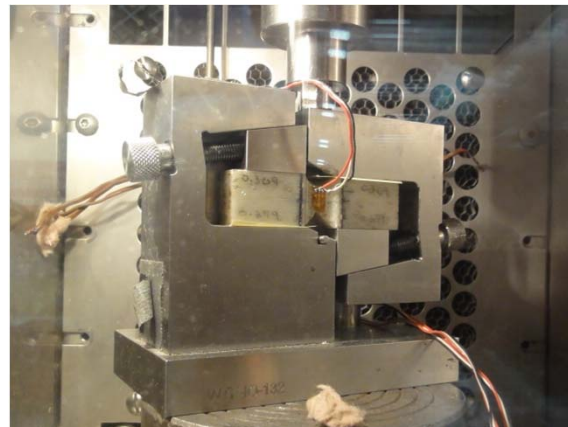
Average Material Properties:

Ultimate Load, P_{max} : 667 lbs
 Shear Strength, S_{xz} : 7,169 psi
 Shear Modulus, G_{xz} : 372,047 psi

Measured Specimen Dimensions:

Depth, D: 0.298 in
 Notch Length, NL: 0.312 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 333 lbs
 20% Max Load: 133 lbs

PICTURE OF SPECIMEN PRE-TEST

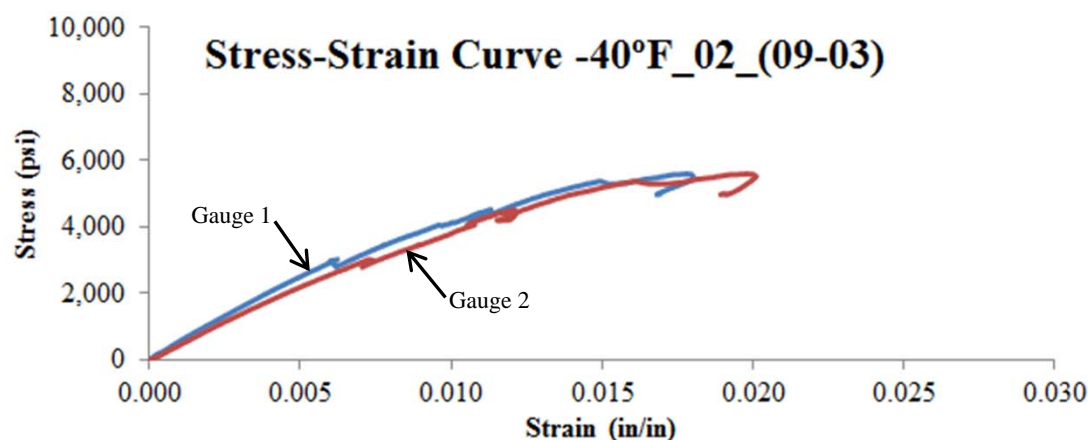


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0081 | 0.0027 | 396,463 |
| 2 | 0.0094 | 0.0032 | 347,631 |
| Average | | | 372,047 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-03-N40-FY09
 Test Date: 8/24/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

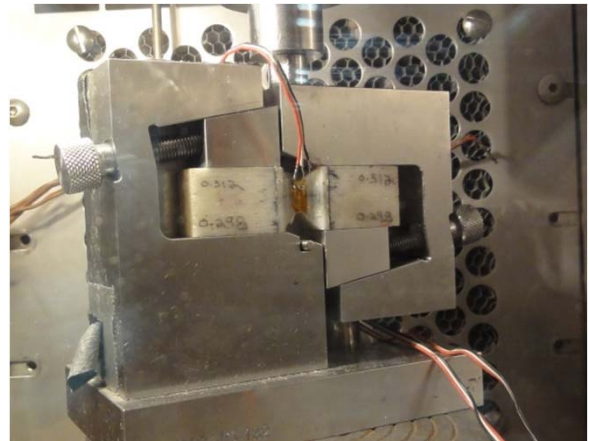
Average Material Properties:

Ultimate Load, P_{max} : 706 lbs
 Shear Strength, S_{xz} : 8,240 psi
 Shear Modulus, G_{xz} : 374,372 psi

Measured Specimen Dimensions:

Depth, D: 0.280 in
 Notch Length, NL: 0.306 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 353 lbs
 20% Max Load: 141 lbs

PICTURE OF SPECIMEN PRE-TEST

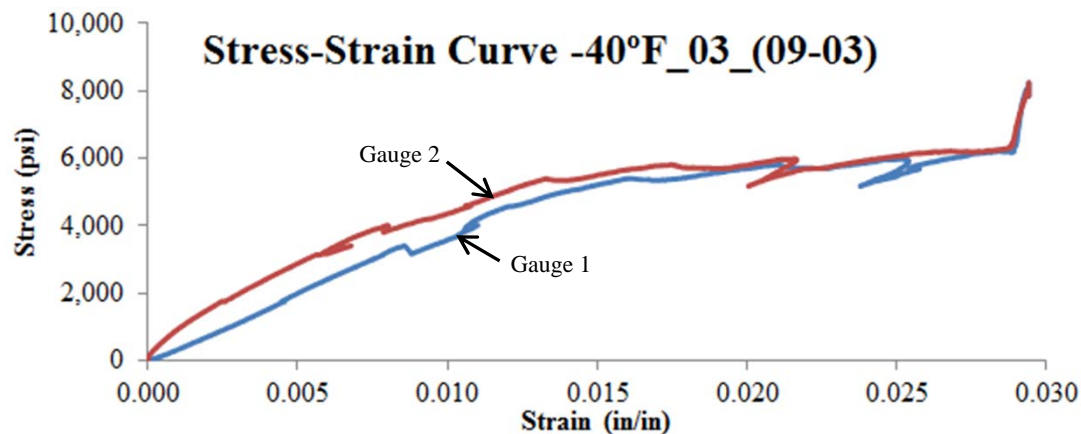


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0108 | 0.0043 | 379,053 |
| 2 | 0.0090 | 0.0023 | 369,691 |
| Average | | | 374,372 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-04-N40-FY09
 Test Date: 8/29/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

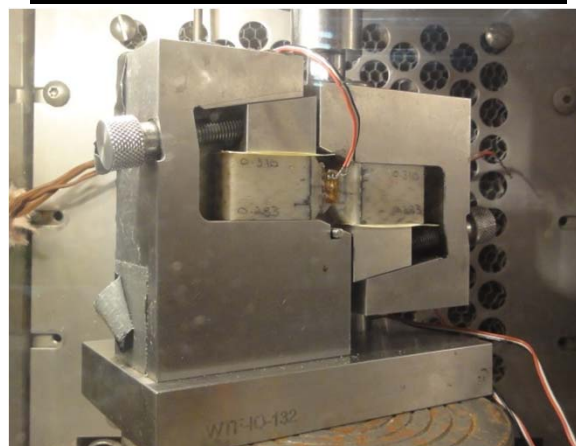
Average Material Properties:

Ultimate Load, P_{max} : 585 lbs
 Shear Strength, S_{xz} : 6,666 psi
 Shear Modulus, G_{xz} : 377,143 psi

Measured Specimen Dimensions:

Depth, D: 0.283 in
 Notch Length, NL: 0.310 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 292 lbs
 20% Max Load: 117 lbs

PICTURE OF SPECIMEN PRE-TEST

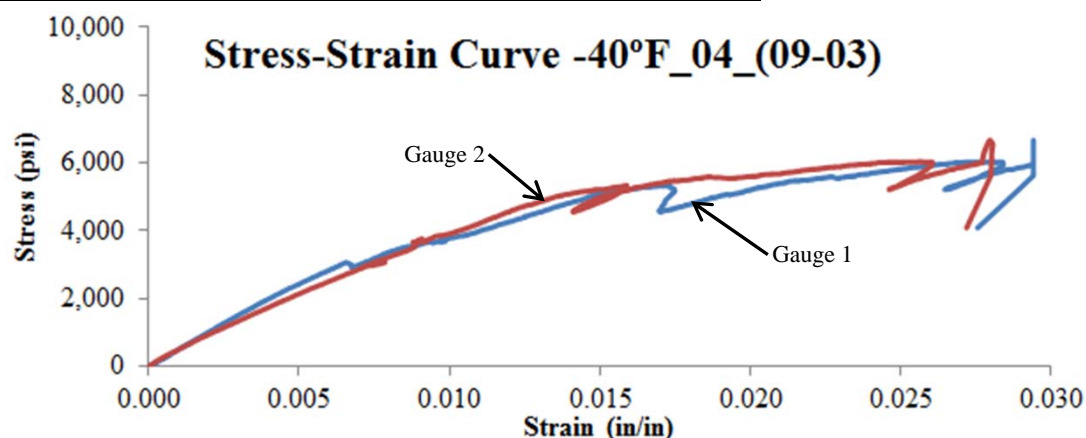


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0079 | 0.0026 | 381,069 |
| 2 | 0.0083 | 0.0030 | 373,218 |
| Average | | | 377,143 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-05-N40-FY09
 Test Date: 8/29/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

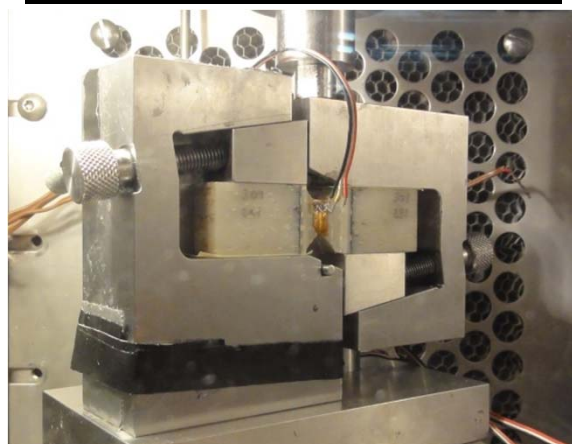
Average Material Properties:

Ultimate Load, P_{max} : 430 lbs
 Shear Strength, S_{xz} : 4,950 psi
 Shear Modulus, G_{xz} : 462,998 psi

Measured Specimen Dimensions:

Depth, D: 0.281 in
 Notch Length, NL: 0.309 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 215 lbs
 20% Max Load: 86 lbs

PICTURE OF SPECIMEN PRE-TEST

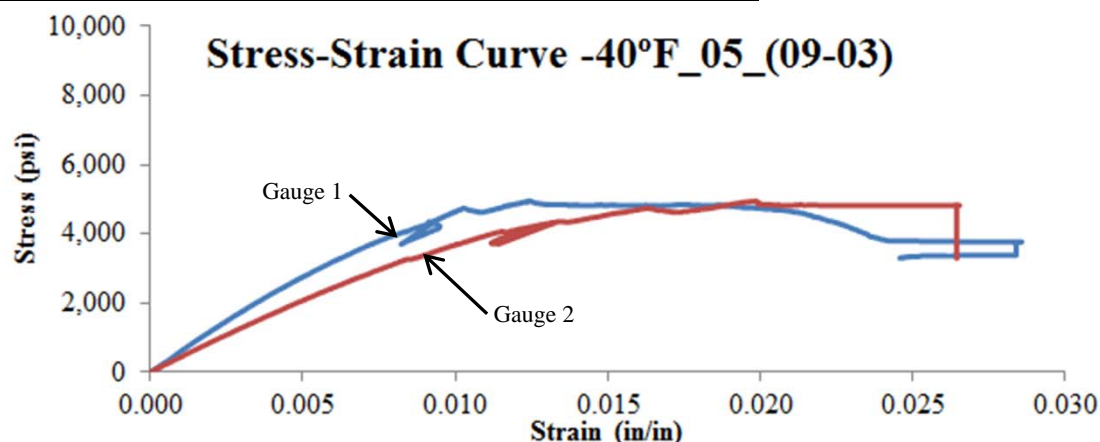


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0044 | 0.0017 | 535,963 |
| 2 | 0.0061 | 0.0023 | 390,033 |
| Average | | | 462,998 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

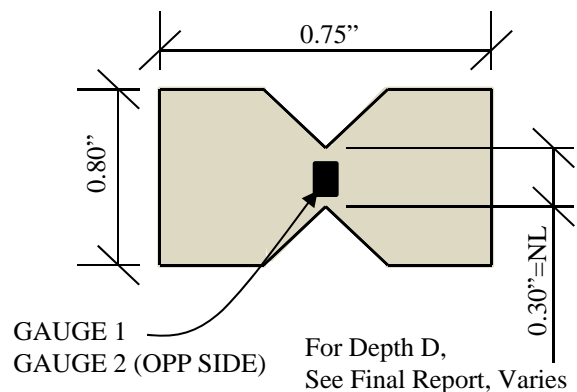
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-SXZ-70-FY09**
 Material: **3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **482** **lbs**
 Shear Strength, S_{xz} : **4,281** **psi**
 Shear Modulus, G_{xz} : **339,945** **psi**

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT3-SXZ-01-70-FY09 | 712 | 4,893 | 355,091 | Shear |
| MAT3-SXZ-02-70-FY09 | 655 | 4,885 | 365,283 | Shear |
| MAT3-SXZ-03-70-FY09 | 307 | 3,585 | 330,128 | Shear |
| MAT3-SXZ-04-70-FY09 | 355 | 4,085 | 301,158 | Shear |
| MAT3-SXZ-05-70-FY09 | 379 | 3,958 | 348,066 | Shear |
| Average | 482 | 4,281 | 339,945 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets F-116 to F-120
- 2) Several specimens had improper failure, 5 valid test results shown.
- 3) All specimens shown failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-01-70-FY09
 Test Date: 7/11/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xz} , G_{xz}

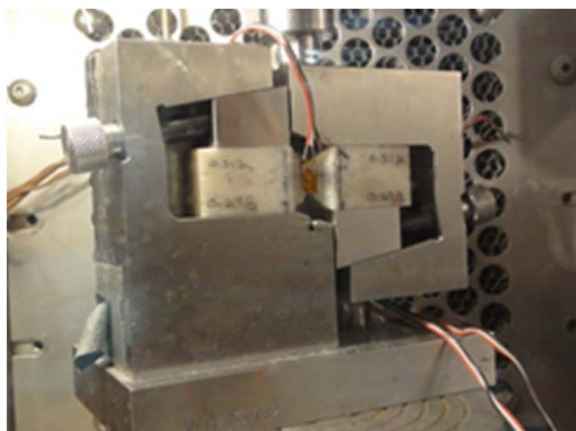
Average Material Properties:

Ultimate Load, P_{max} : 712 lbs
 Shear Strength, S_{xz} : 4,893 psi
 Shear Modulus, G_{xz} : 355,091 psi

Measured Specimen Dimensions:

Depth, D: 0.493 in
 Notch Length, NL: 0.295 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 356 lbs
 20% Max Load: 142 lbs

PICTURE OF SPECIMEN PRE-TEST

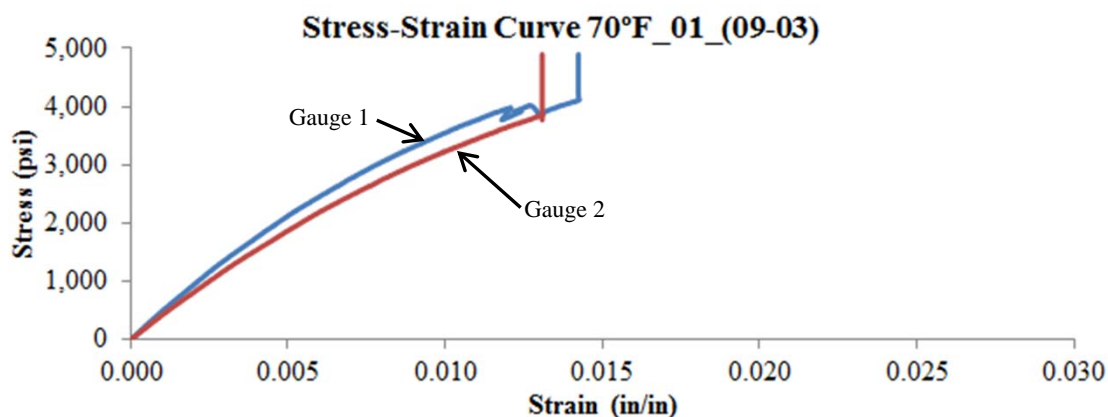


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0060 | 0.0021 | 379,738 |
| 2 | 0.0069 | 0.0025 | 330,444 |
| Average | | | 355,091 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-02-70-FY09
 Test Date: 7/31/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xz} , G_{xz}

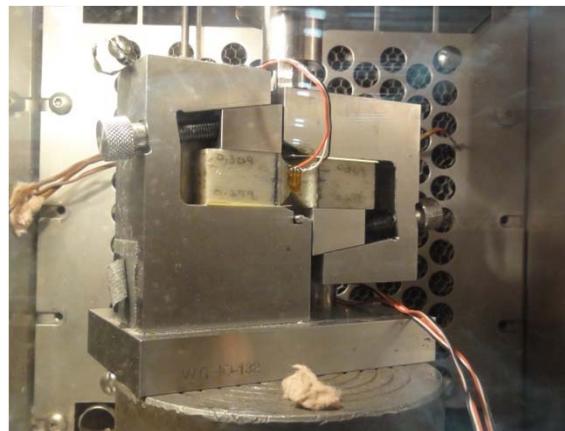
Average Material Properties:

Ultimate Load, P_{max} : 655 lbs
 Shear Strength, S_{xz} : 4,885 psi
 Shear Modulus, G_{xz} : 365,283 psi

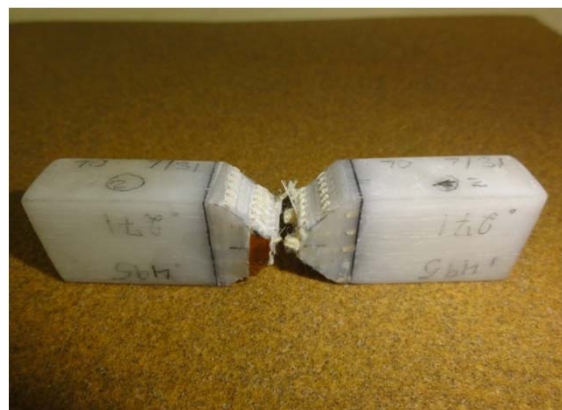
Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.271 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 328 lbs
 20% Max Load: 131 lbs

PICTURE OF SPECIMEN PRE-TEST

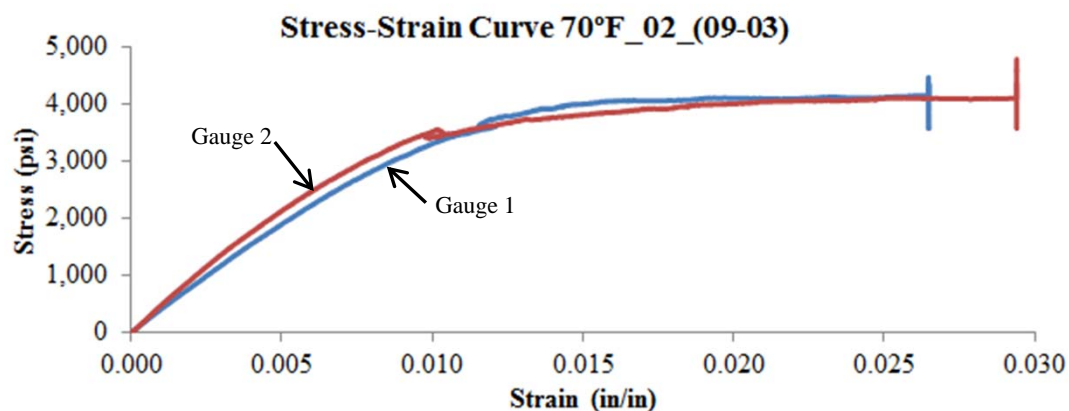


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0066 | 0.0024 | 347,834 |
| 2 | 0.0059 | 0.0021 | 382,731 |
| Average | | | 365,283 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-03-70-FY09
 Test Date: 8/23/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

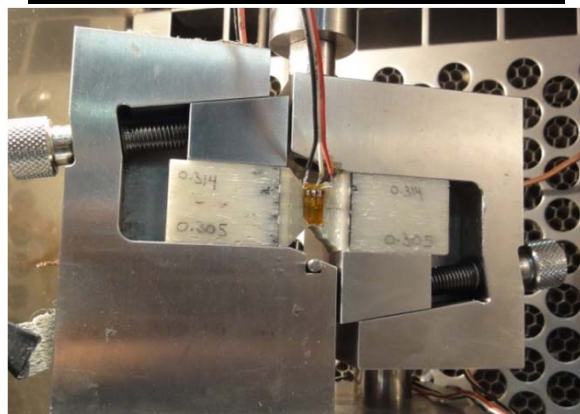
Average Material Properties:

Ultimate Load, P_{max} : 307 lbs
 Shear Strength, S_{xz} : 3,585 psi
 Shear Modulus, G_{xz} : 330,128 psi

Measured Specimen Dimensions:

Depth, D: 0.281 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 154 lbs
 20% Max Load: 61 lbs

PICTURE OF SPECIMEN PRE-TEST

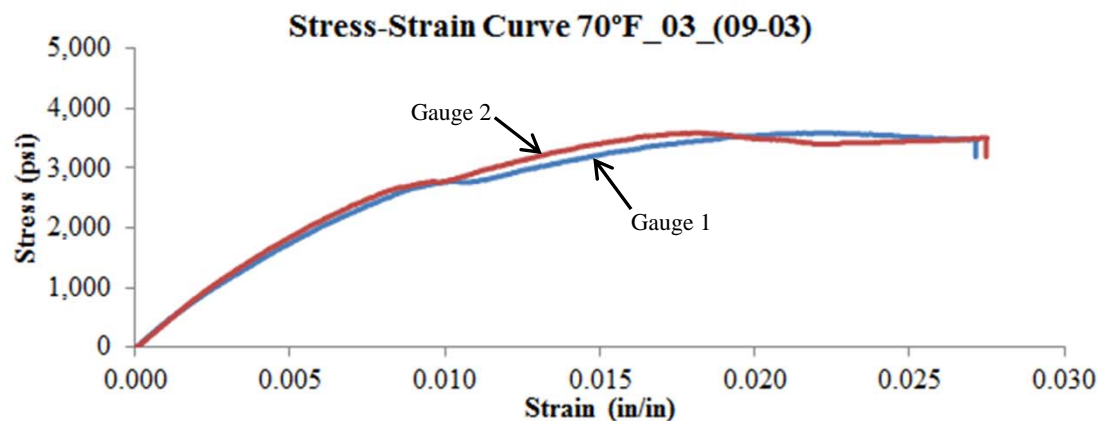


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0017 | 315,285 |
| 2 | 0.0048 | 0.0017 | 344,971 |
| Average | | | 330,128 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-04-70-FY09
 Test Date: 8/23/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

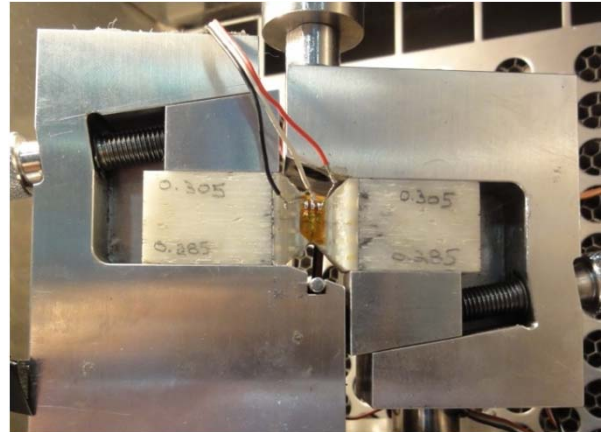
Average Material Properties:

Ultimate Load, P_{max} : 355 lbs
 Shear Strength, S_{xz} : 4,085 psi
 Shear Modulus, G_{xz} : 301,158 psi

Measured Specimen Dimensions:

Depth, D: 0.285 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 178 lbs
 20% Max Load: 71 lbs

PICTURE OF SPECIMEN PRE-TEST

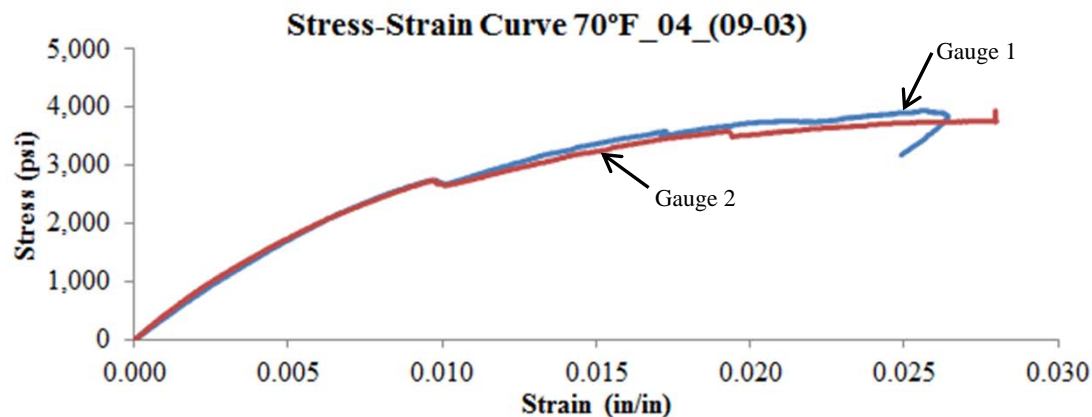


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0062 | 0.0022 | 307,200 |
| 2 | 0.0062 | 0.0020 | 295,116 |
| Average | | | 301,158 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-05-70-FY09
 Test Date: 8/24/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

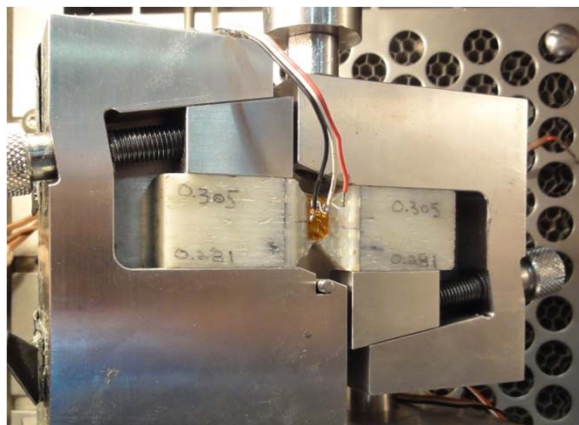
Average Material Properties:

Ultimate Load, P_{max} : 379 lbs
 Shear Strength, S_{xz} : 3,958 psi
 Shear Modulus, G_{xz} : 348,066 psi

Measured Specimen Dimensions:

Depth, D: 0.314 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 190 lbs
 20% Max Load: 76 lbs

PICTURE OF SPECIMEN PRE-TEST

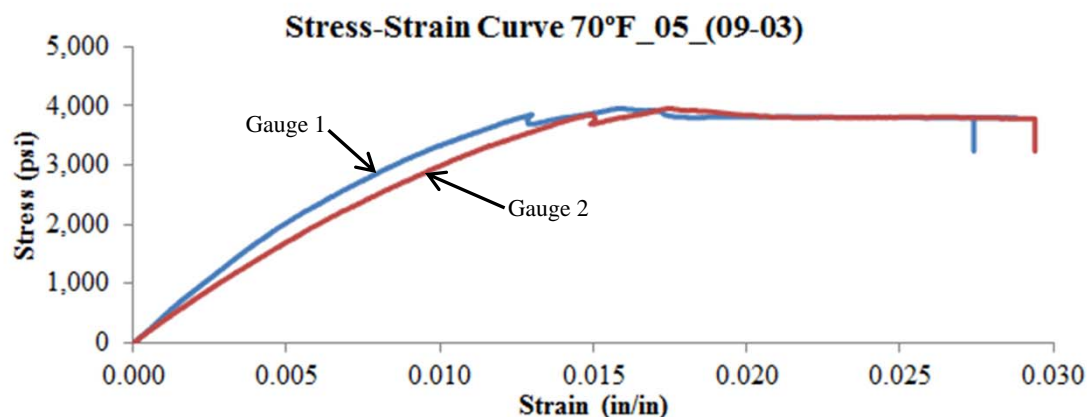


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0048 | 0.0017 | 383,145 |
| 2 | 0.0059 | 0.0021 | 312,988 |
| Average | | | 348,066 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-SXZ-140-FY09**
 Material: **3D Hybrid Panels, S2-Glass w/ Aramid Z-Fiber**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **263** **lbs**
 Shear Strength, S_{xz} : **3,389** **psi**
 Shear Modulus, G_{xz} : **213,580** **psi**

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT3-SXZ-01-140-FY09 | 269 | 3,082 | 205,688 | Shear |
| MAT3-SXZ-02-140-FY09 | 321 | 4,253 | 180,165 | Shear |
| MAT3-SXZ-03-140-FY09 | 218 | 2,888 | 238,692 | Shear |
| MAT3-SXZ-04-140-FY09 | 273 | 3,591 | 207,859 | Shear |
| MAT3-SXZ-05-140-FY09 | 234 | 3,132 | 235,496 | Shear |
| Average | 263 | 3,389 | 213,580 | |

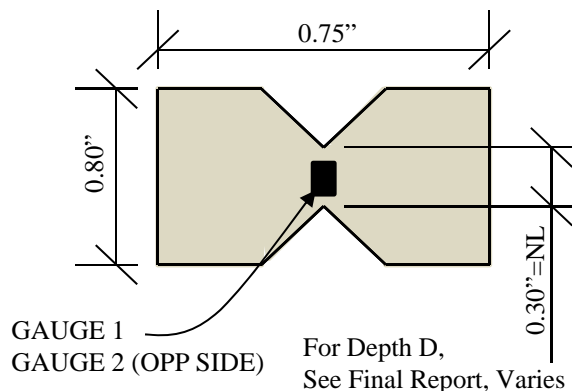
Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets F-122 to F-126
- 2) Five specimens tested with the results shown.
- 3) All specimens shown failed in shear at the specimen notch

F-121

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-01-140-FY09
 Test Date: 8/20/2012
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

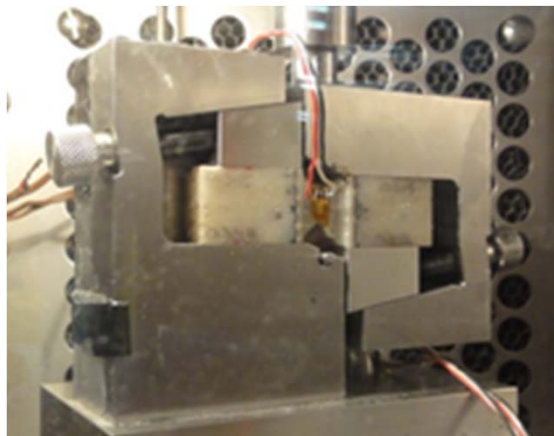
Average Material Properties:

Ultimate Load, P_{max} : 269 lbs
 Shear Strength, S_{xz} : 3,082 psi
 Shear Modulus, G_{xz} : 205,688 psi

Measured Specimen Dimensions:

Depth, D: 0.279 in
 Notch Length, NL: 0.313 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 135 lbs
 20% Max Load: 54 lbs

PICTURE OF SPECIMEN PRE-TEST

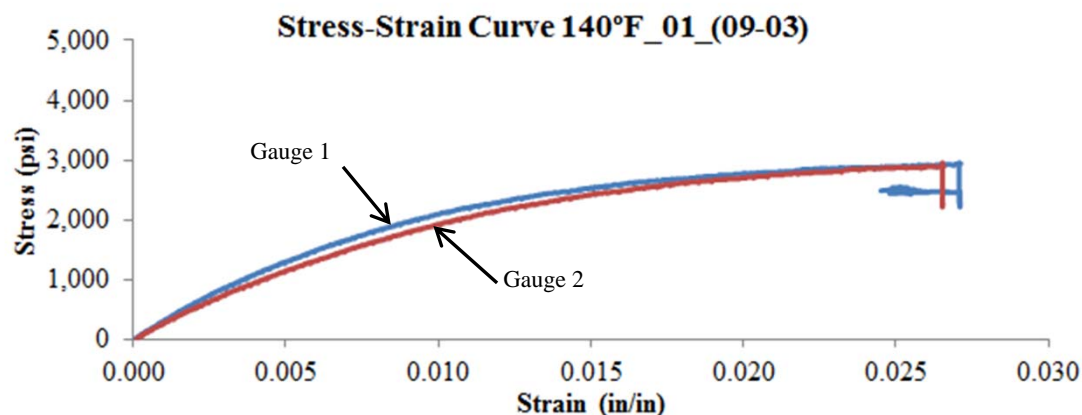


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0063 | 0.0021 | 220,458 |
| 2 | 0.0073 | 0.0025 | 190,919 |
| Average | | | 205,688 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-02-140-FY09
 Test Date: 8/22/2012
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

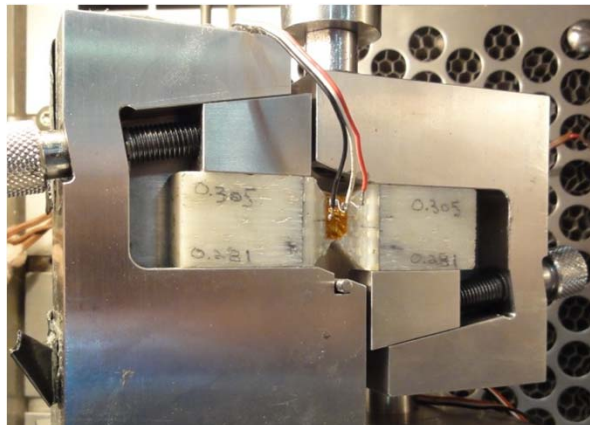
Average Material Properties:

Ultimate Load, P_{max} : 321 lbs
 Shear Strength, S_{xz} : 4,253 psi
 Shear Modulus, G_{xz} : 180,165 psi

Measured Specimen Dimensions:

Depth, D: 0.251 in
 Notch Length, NL: 0.301 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 161 lbs
 20% Max Load: 64 lbs

PICTURE OF SPECIMEN PRE-TEST

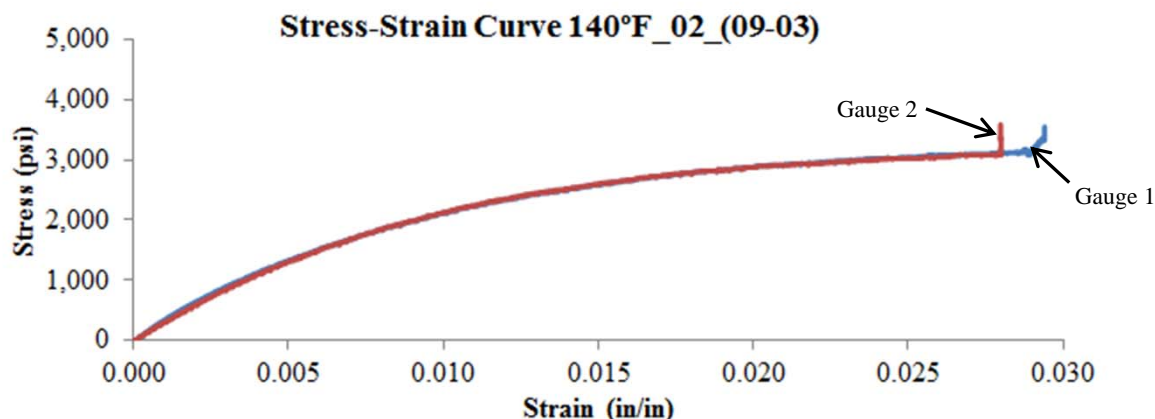


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0100 | 0.0028 | 177,083 |
| 2 | 0.0100 | 0.0030 | 183,247 |
| Average | | | 180,165 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-03-140-FY09
 Test Date: 8/23/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

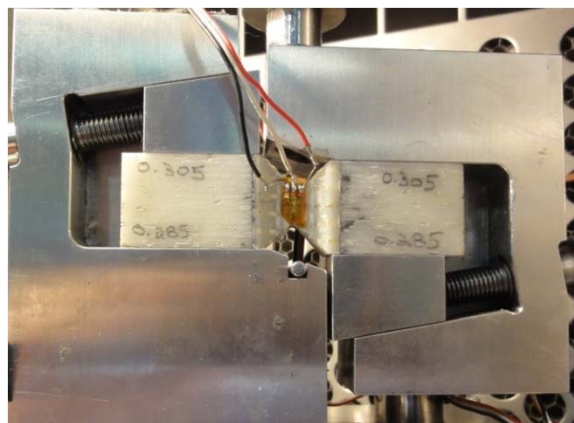
Average Material Properties:

Ultimate Load, P_{max} : 218 lbs
 Shear Strength, S_{xz} : 2,888 psi
 Shear Modulus, G_{xz} : 238,692 psi

Measured Specimen Dimensions:

Depth, D: 0.248 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 109 lbs
 20% Max Load: 44 lbs

PICTURE OF SPECIMEN PRE-TEST

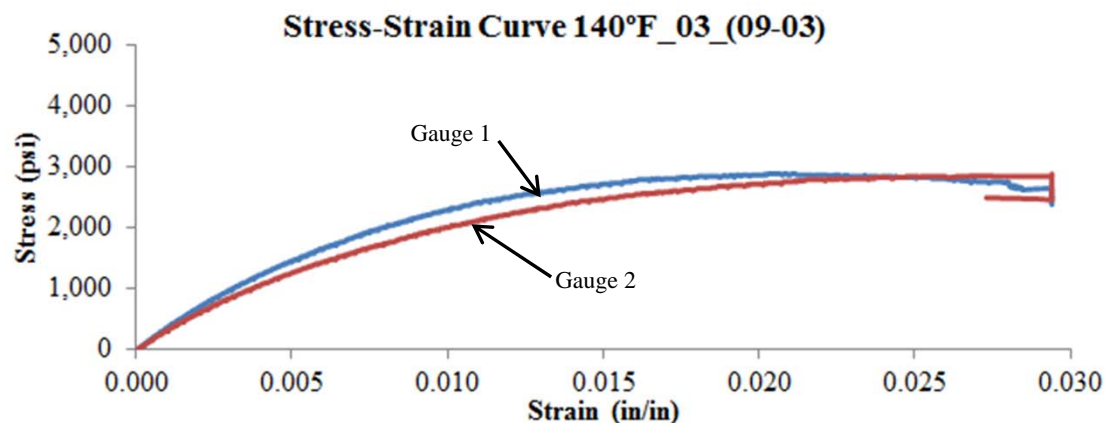


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0049 | 0.0017 | 265,019 |
| 2 | 0.0060 | 0.0019 | 212,365 |
| Average | | | 238,692 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-04-140-FY09
 Test Date: 8/23/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

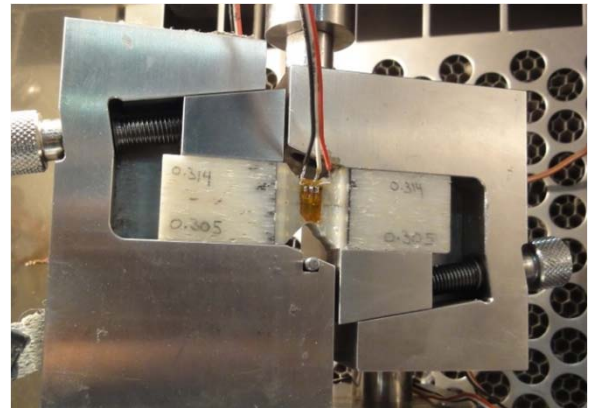
Average Material Properties:

Ultimate Load, P_{max} : 273 lbs
 Shear Strength, S_{xz} : 3,591 psi
 Shear Modulus, G_{xz} : 207,859 psi

Measured Specimen Dimensions:

Depth, D: 0.248 in
 Notch Length, NL: 0.307 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 137 lbs
 20% Max Load: 55 lbs

PICTURE OF SPECIMEN PRE-TEST

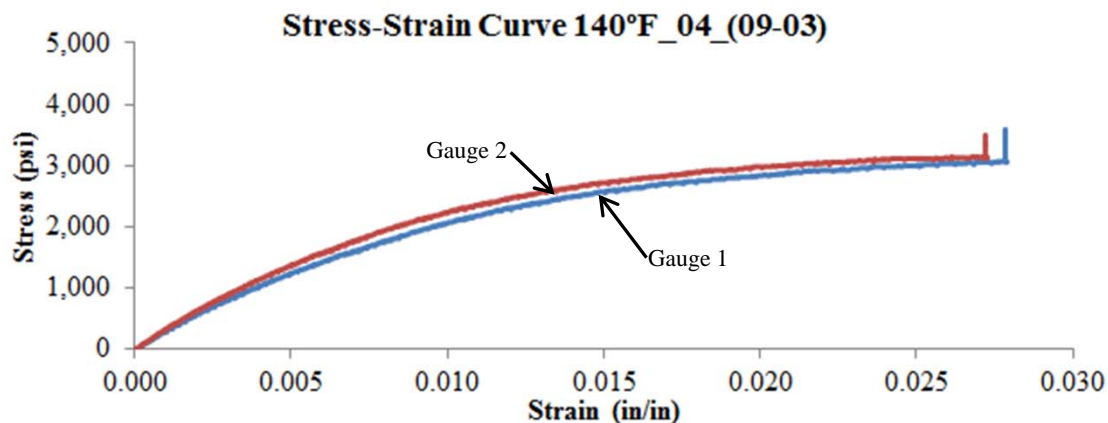


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0082 | 0.0026 | 193,049 |
| 2 | 0.0071 | 0.0023 | 222,669 |
| Average | | | 207,859 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT3-SXZ-05-140-FY09
 Test Date: 8/23/12
 Specimen Received: 8/6/2012
 Properties Measured: S_{xz} , G_{xz}

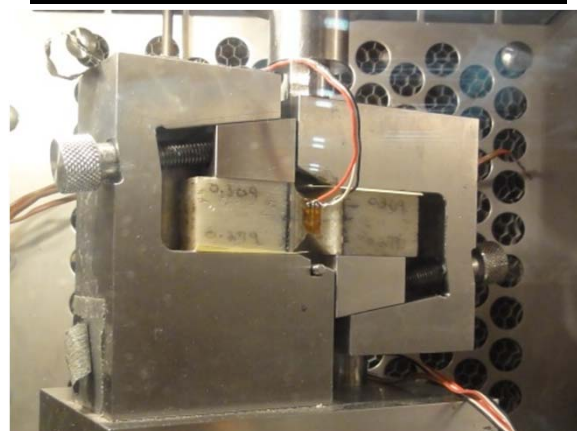
Average Material Properties:

Ultimate Load, P_{max} : 234 lbs
 Shear Strength, S_{xz} : 3,132 psi
 Shear Modulus, G_{xz} : 235,496 psi

Measured Specimen Dimensions:

Depth, D: 0.249 in
 Notch Length, NL: 0.300 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 117 lbs
 20% Max Load: 47 lbs

PICTURE OF SPECIMEN PRE-TEST

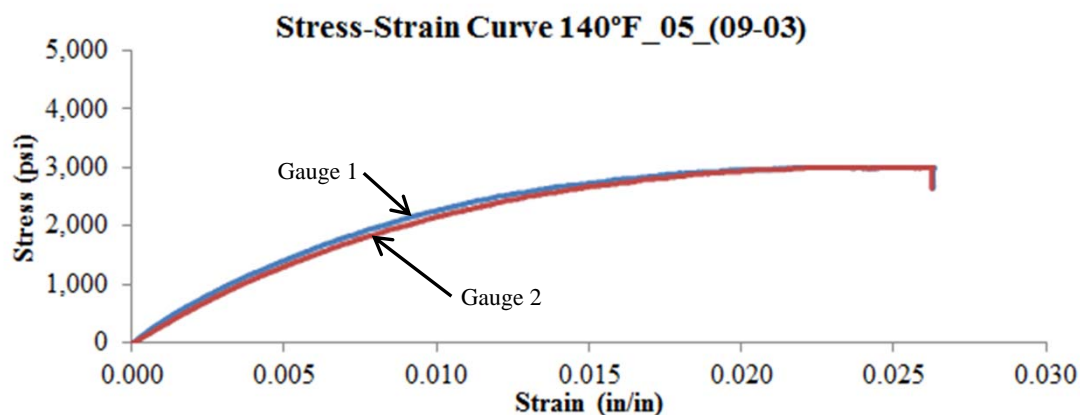


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0057 | 0.0018 | 242,405 |
| 2 | 0.0063 | 0.0022 | 228,588 |
| Average | | | 235,496 |



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

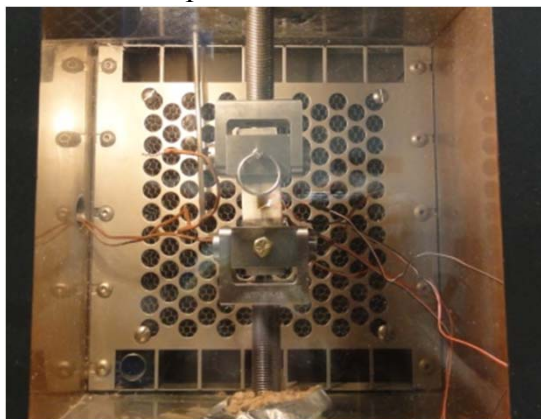
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT3-OP-N40-FY09
 Material: 3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers
 Nominal Temperature: -40°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1036
 Maximum Load, P_z : 7,782 lbs

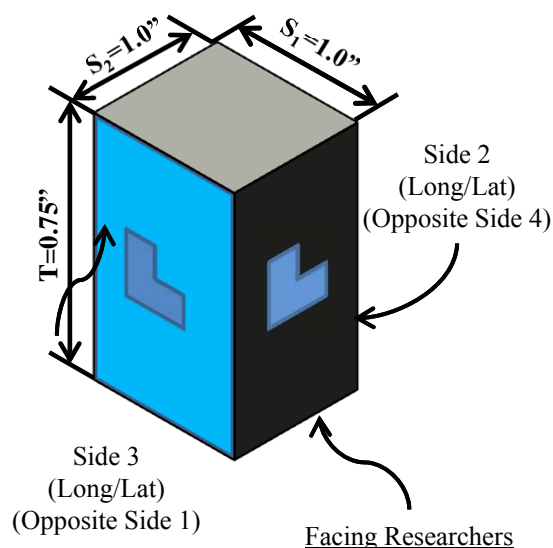
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT3-OP-1-N40-FY09 | 7,796 | 0.0937 | Bondline |
| 2 | MAT3-OP-2-N40-FY09 | 7,781 | 0.1002 | Bondline |
| 3 | MAT3-OP-3-N40-FY09 | 7,781 | 0.1137 | Bondline |
| 4 | MAT3-OP-4-N40-FY09 | 7,765 | 0.1198 | Bondline |
| 5 | MAT3-OP-5-N40-FY09 | 7,789 | 0.0904 | Bondline |
| Average | | 7,782 | 0.1036 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The blocks nominal dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) Reference F-128 thru F-132 for individual specimen data.
- 2) 7 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-01-N40-FY09**
 Test Date: 8/29/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

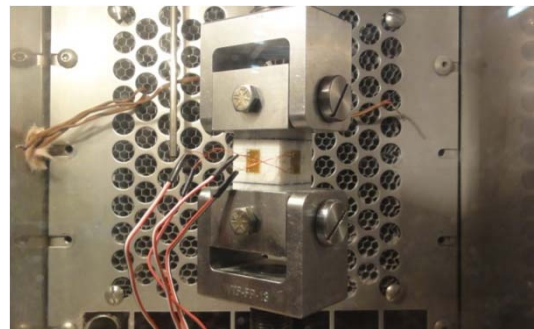
Maximum Load, P_z : 7,796 lbs
 Poisson's Ratio, v_{xz} : 0.0937

Measured Specimen Dimensions:

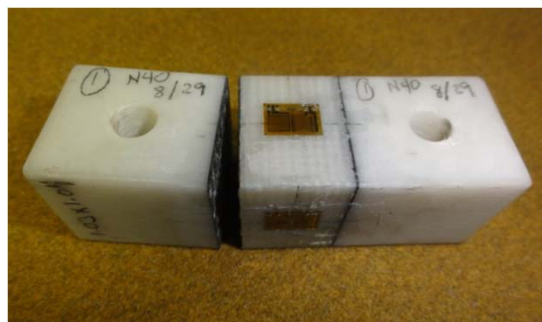
Thickness: 0.750 in
 Side 1: 1.003 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 3,898 lbs
 20% Max Load: 1,559 lbs

PICTURE OF SPECIMEN PRE-TEST



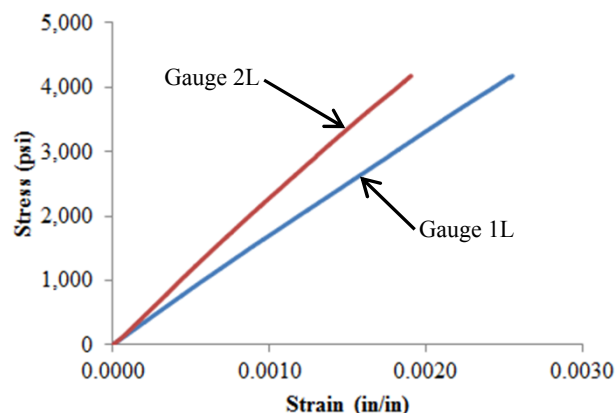
PICTURE OF SPECIMEN POST-TEST



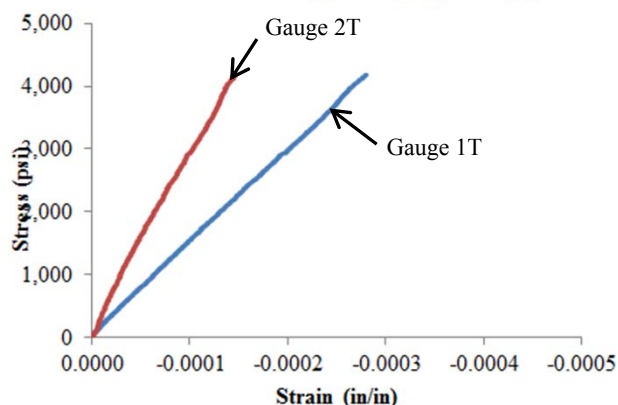
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002352 | 0.000907 | 1T | -0.000258 | -0.000100 | 0.1089 |
| 2L | 0.001755 | 0.000671 | 2T | -0.000133 | -0.000048 | 0.0786 |
| Average | | | | | | 0.0937 |

Stress-Strain Curve _-40°C_1_(09-03)_Long



Stress-Strain Curve _-40°C_1_(09-03)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-02-N40-FY09**
 Test Date: 8/29/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

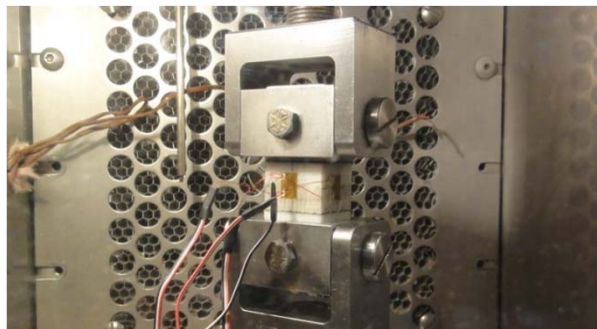
Maximum Load, P_z : 7,781 lbs
 Poisson's Ratio, v_{xz} : 0.1002

Measured Specimen Dimensions:

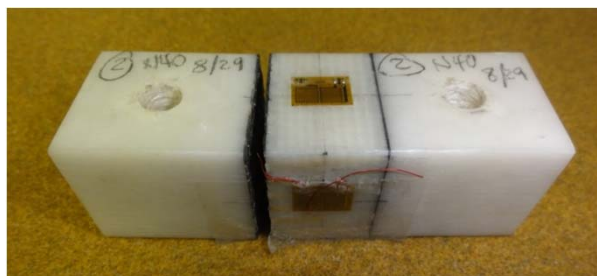
Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 3,890 lbs
 20% Max Load: 1,556 lbs

PICTURE OF SPECIMEN PRE-TEST



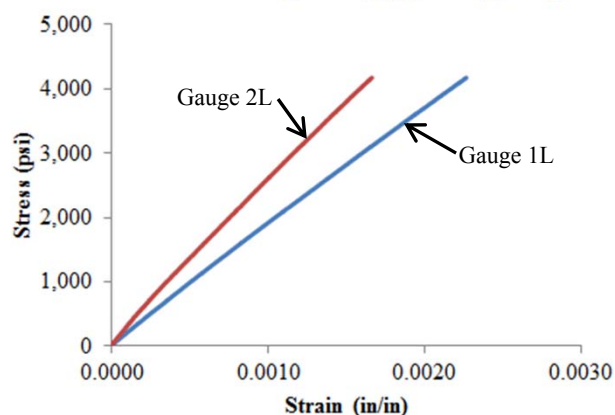
PICTURE OF SPECIMEN POST-TEST



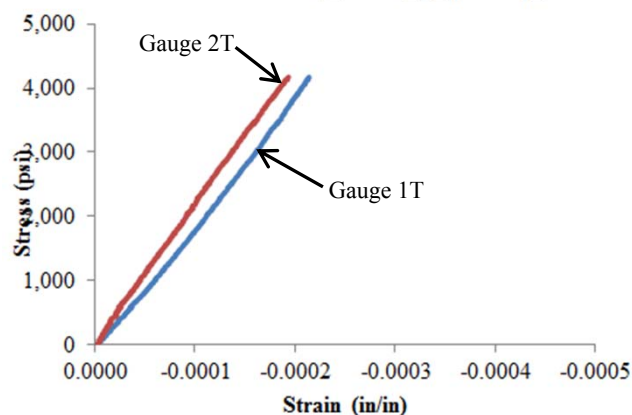
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002094 | 0.000800 | 1T | -0.000201 | -0.000088 | 0.0870 |
| 2L | 0.001530 | 0.000572 | 2T | -0.000179 | -0.000070 | 0.1134 |
| Average | | | | | | 0.1002 |

Stress-Strain Curve _-40°C_2_(09-03)_Long



Stress-Strain Curve _-40°C_2_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-03-N40-FY09**
 Test Date: 8/30/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

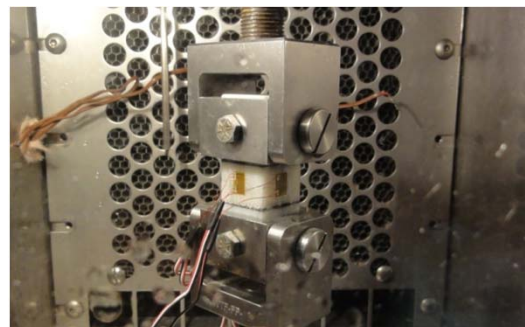
Maximum Load, P_z : 7,781 lbs
 Poisson's Ratio, v_{xz} : 0.1137

Measured Specimen Dimensions:

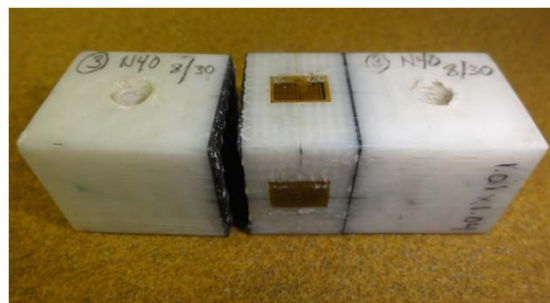
Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 3,890 lbs
 20% Max Load: 1,556 lbs

PICTURE OF SPECIMEN PRE-TEST



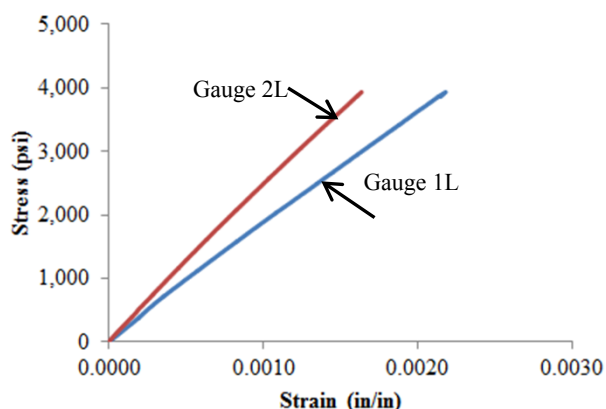
PICTURE OF SPECIMEN POST-TEST



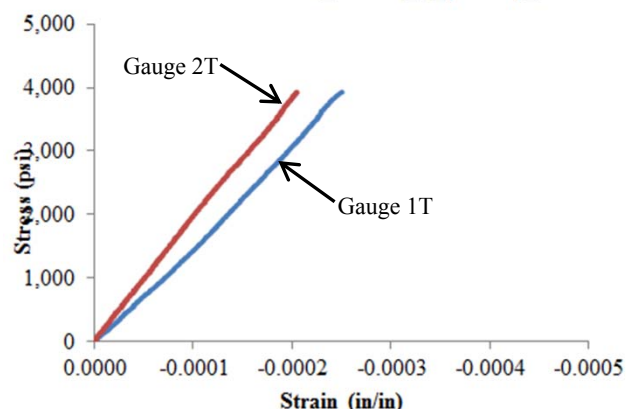
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002140 | 0.000812 | 1T | -0.000245 | -0.000107 | 0.1038 |
| 2L | 0.001608 | 0.000607 | 2T | -0.000201 | -0.000078 | 0.1237 |
| Average | | | | | | 0.1137 |

Stress-Strain Curve _40°C_3_(09-03)_Long



Stress-Strain Curve _40°C_3_(09-03)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-03-N40-FY09**
 Test Date: 8/30/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

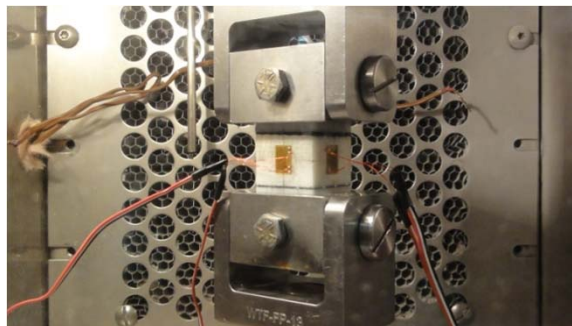
Maximum Load, P_z : 7,765 lbs
 Poisson's Ratio, v_{xz} : 0.1198

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.003 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 3,883 lbs
 20% Max Load: 1,553 lbs

PICTURE OF SPECIMEN PRE-TEST



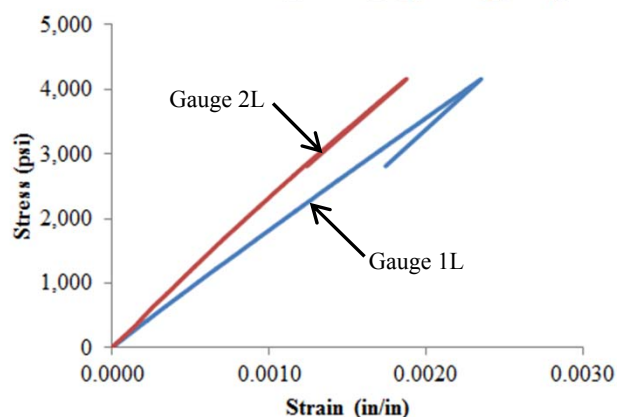
PICTURE OF SPECIMEN POST-TEST



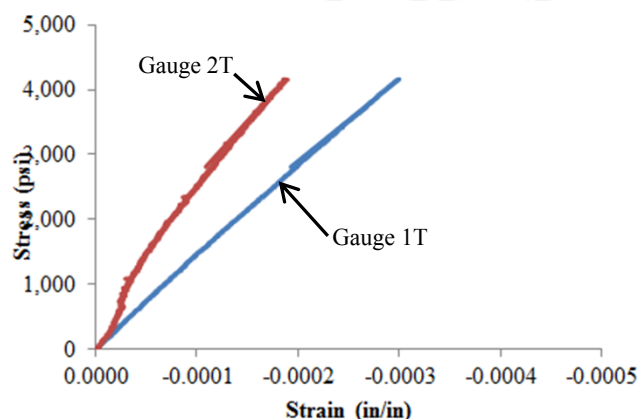
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002185 | 0.000848 | 1T | -0.000277 | -0.000107 | 0.1276 |
| 2L | 0.001733 | 0.000652 | 2T | -0.000174 | -0.000053 | 0.1121 |
| Average | | | | | | 0.1198 |

Stress-Strain Curve _-40°C_4_(09-03)_Long



Stress-Strain Curve _-40°C_4_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-05-N40-FY09**
 Test Date: 8/30/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

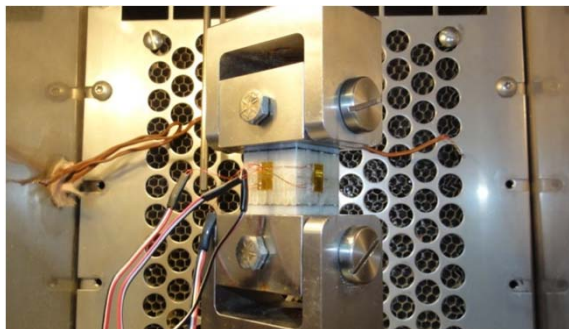
Maximum Load, P_z : 7,789 lbs
 Poisson's Ratio, v_{xz} : 0.0904

Measured Specimen Dimensions:

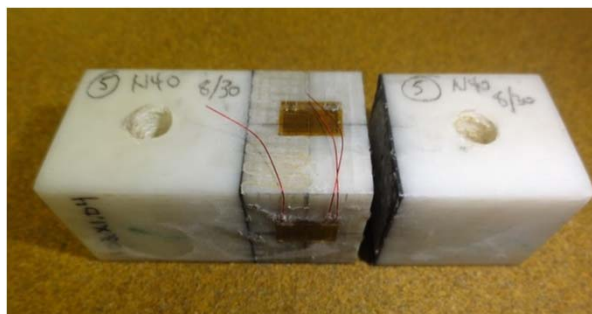
Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 3,894 lbs
 20% Max Load: 1,558 lbs

PICTURE OF SPECIMEN PRE-TEST

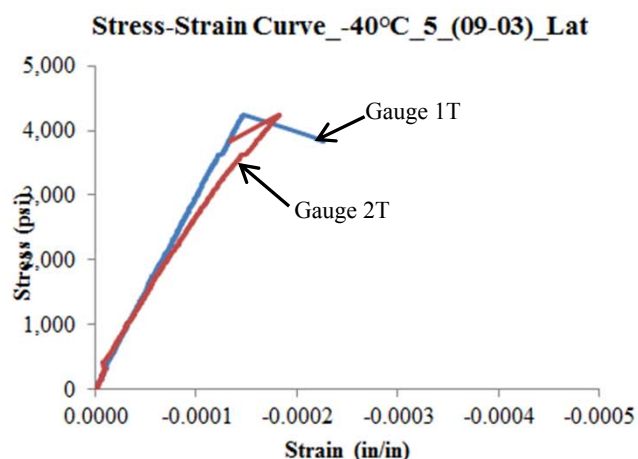
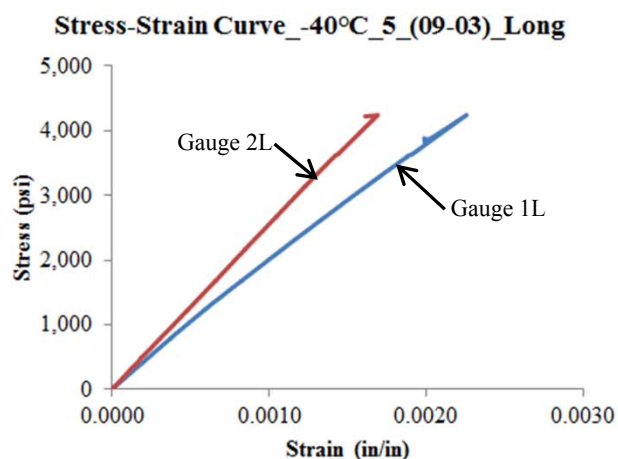


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.002044 | 0.000755 | 1T | -0.000134 | -0.000051 | 0.0639 |
| 2L | 0.001537 | 0.000607 | 2T | -0.000162 | -0.000053 | 0.1169 |
| Average | | | | | | 0.0904 |



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

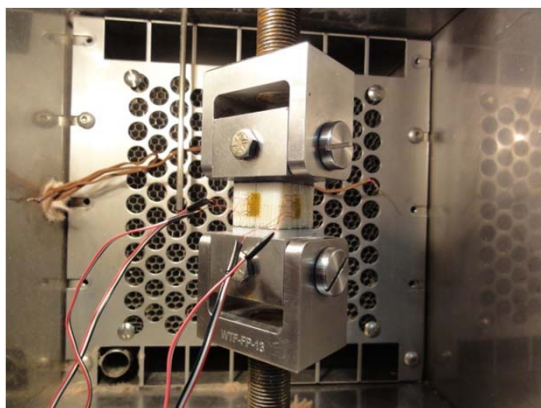
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-OP-70-FY09**
 Material: **3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers**
 Nominal Temperature: **70°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.1265**
 Maximum Load, P_z : **7,011 lbs**

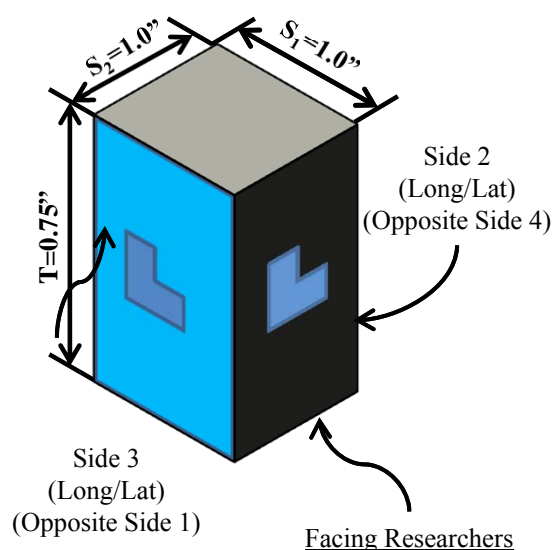
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|-------------------|-------------------------|--------------------------------|-----------------|
| 1 | MAT3-OP-1-70-FY09 | 6,982 | 0.1120 | Bondline |
| 2 | MAT3-OP-2-70-FY09 | 7,024 | 0.1165 | Bondline |
| 3 | MAT3-OP-3-70-FY09 | 7,031 | 0.1422 | Bondline |
| 4 | MAT3-OP-4-70-FY09 | 7,024 | 0.1344 | Bondline |
| 5 | MAT3-OP-5-70-FY09 | 6,996 | 0.1274 | Bondline |
| Average | | 7,011 | 0.1265 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The blocks nominal dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) Reference F-134 thru F-138 for individual specimen data.
- 2) 6 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-01-70-FY09**
 Test Date: 8/22/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

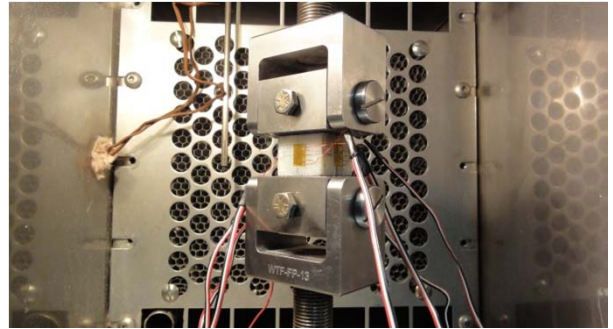
Maximum Load, P_z : 6,982 lbs
 Poisson's Ratio, v_{xz} : 0.1120

Measured Specimen Dimensions:

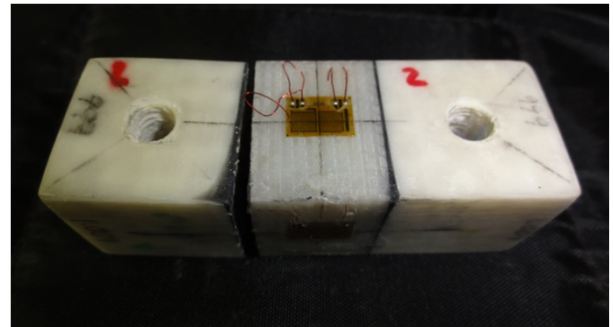
Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 0.999 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 40% Max Load: 2,793 lbs
 10% Max Load: 698 lbs

PICTURE OF SPECIMEN PRE-TEST



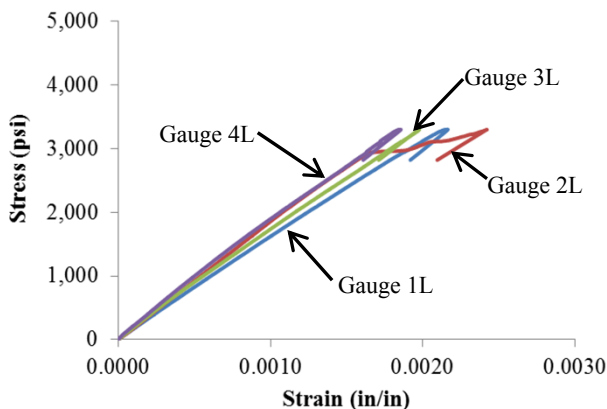
PICTURE OF SPECIMEN POST-TEST



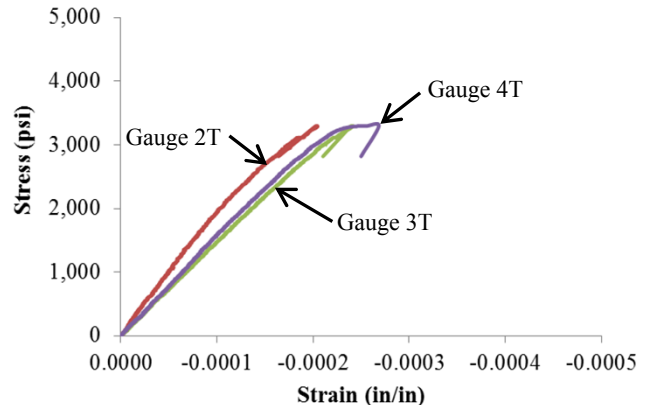
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | |
|--------------------|--------------------------|--------------------------|---------------|--------------------------|--------------------------|-----------------|
| Gauge | Strain @ 40% Max Load | Strain @ 10% Max Load | Gauge | Strain @ 40% Max Load | Strain @ 10% Max Load | Poisson's Ratio |
| | (in/in) | (in/in) | | (in/in) | (in/in) | v_{xz} |
| 1L | 0.001767 | 0.000423 | 1T | Lost Gauge | | |
| 2L | 0.001553 | 0.000380 | 2T | -0.000158 | -0.000034 | 0.1050 |
| 3L | 0.001662 | 0.000381 | 3T | -0.000194 | -0.000047 | 0.1147 |
| 4L | 0.001543 | 0.000344 | 4T | -0.000185 | -0.000045 | 0.1163 |
| Average | | | | | | 0.1120 |

Stress-Strain Curve_70°F_1_(09-03)_Long



Stress-Strain Curve_70°F_1_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges on all sides.
- *Poisson's Ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-02-70-FY09**
 Test Date: 9/18/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 7,024 lbs
 Poisson's Ratio, v_{xz} : 0.1165

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.003 in
 Side 2: 1.003 in

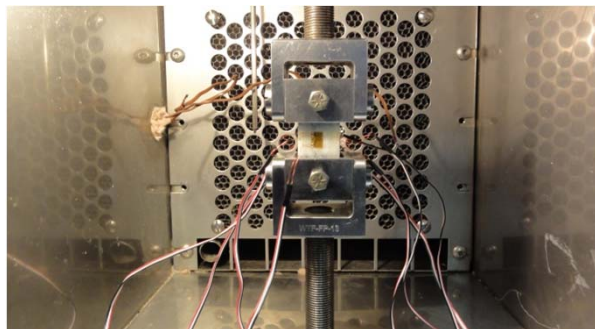
Laboratory Temperature: 68°F

Failure Mode: Bondline

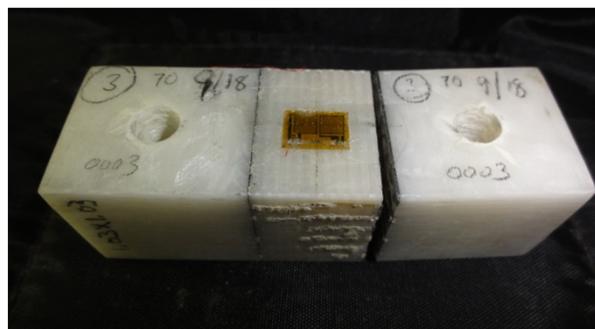
40% Max Load: 2,810 lbs

10% Max Load: 702 lbs

PICTURE OF SPECIMEN PRE-TEST



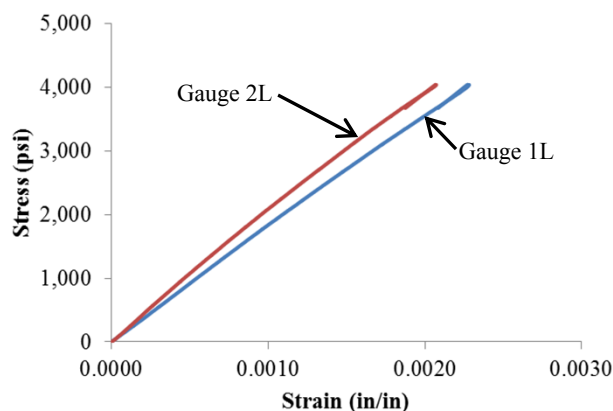
PICTURE OF SPECIMEN POST-TEST



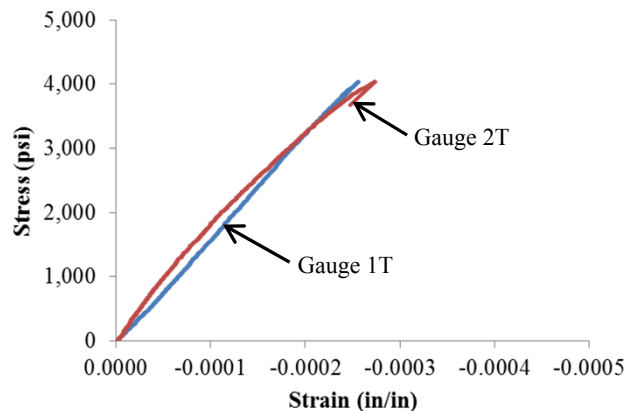
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001547 | 0.000383 | 1T | -0.000172 | -0.000047 | 0.1073 |
| 2L | 0.001371 | 0.000323 | 2T | -0.000166 | -0.000035 | 0.1257 |
| Average | | | | | | 0.1165 |

Stress-Strain Curve_70°F_2_(09-03)_Long



Stress-Strain Curve_70°F_2_(09-03)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 10% and 40% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-03-70-FY09**
 Test Date: 9/18/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

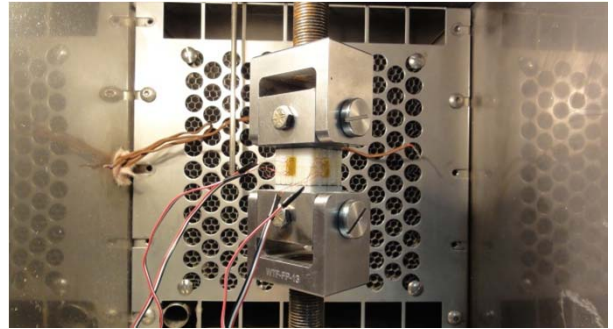
Maximum Load, P_z : 7,031 lbs
 Poisson's Ratio, v_{xz} : 0.1422

Measured Specimen Dimensions:

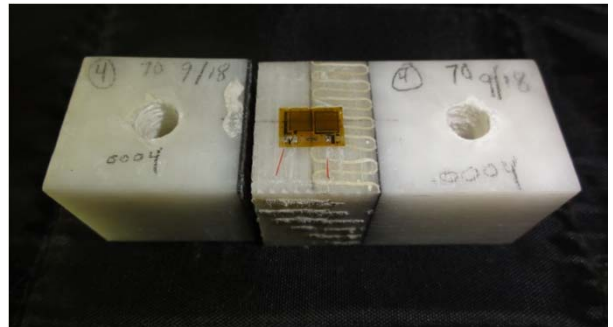
Thickness: 0.750 in
 Side 1: 1.005 in
 Side 2: 1.002 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 40% Max Load: 2,812 lbs
 10% Max Load: 703 lbs

PICTURE OF SPECIMEN PRE-TEST

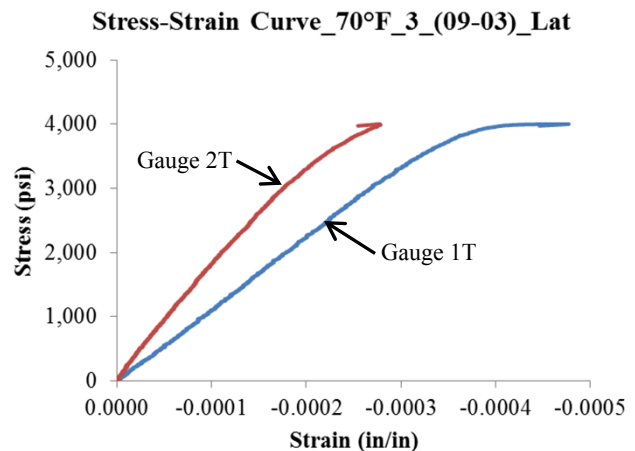
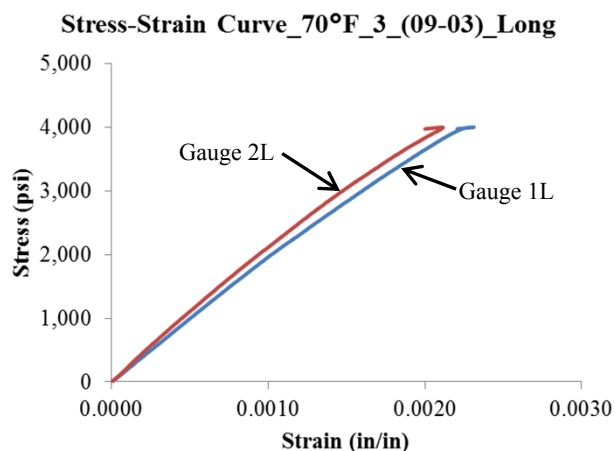


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001476 | 0.000352 | 1T | -0.000249 | -0.000064 | 0.1641 |
| 2L | 0.001358 | 0.000309 | 2T | -0.000162 | -0.000035 | 0.1203 |
| Average | | | | | | 0.1422 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-04-70-FY09**
 Test Date: 9/18/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 7,024 lbs
 Poisson's Ratio, v_{xz} : 0.1344

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.004 in
 Side 2: 1.002 in

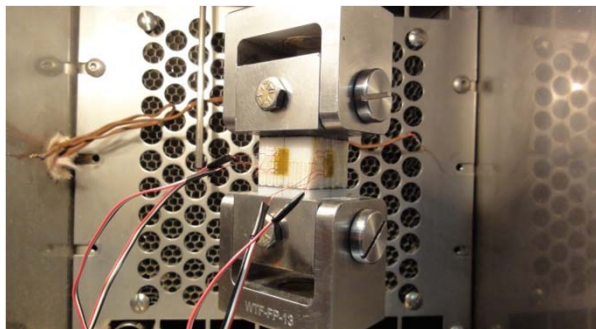
Laboratory Temperature: 68°F

Failure Mode: Bondline

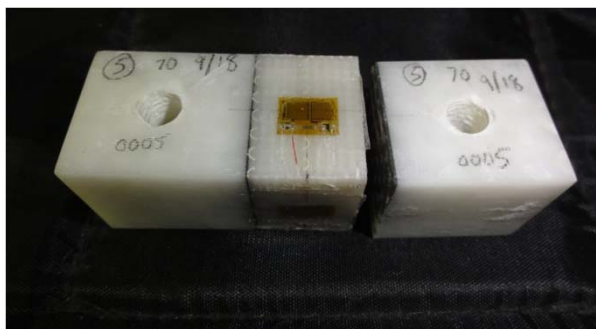
40% Max Load: 2,810 lbs

10% Max Load: 702 lbs

PICTURE OF SPECIMEN PRE-TEST



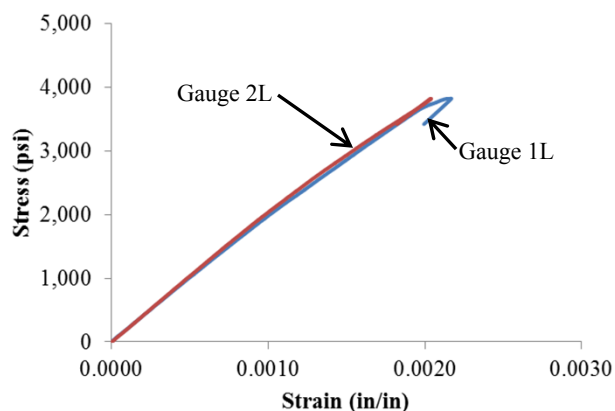
PICTURE OF SPECIMEN POST-TEST



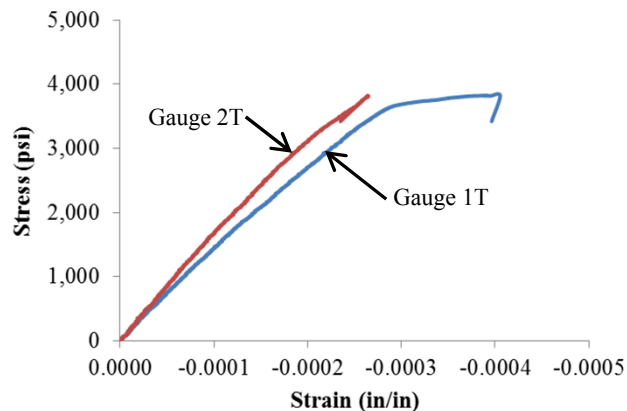
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001461 | 0.000343 | 1T | -0.000208 | -0.000047 | 0.1438 |
| 2L | 0.001417 | 0.000338 | 2T | -0.000176 | -0.000041 | 0.1251 |
| Average | | | | | | 0.1344 |

Stress-Strain Curve_70°F_4_(09-03)_Long



Stress-Strain Curve_70°F_4_(09-03)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.

*Poisson's Ratio was calculated using strain at 10% and 40% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-05-70-FY09**
 Test Date: 9/18/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

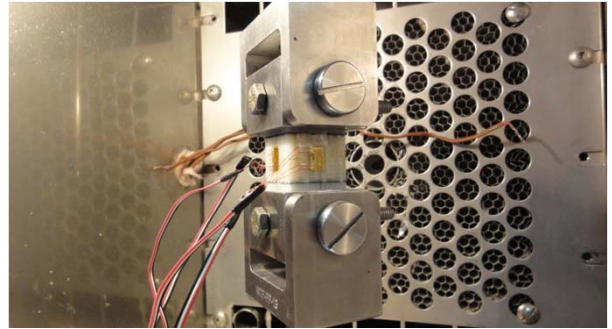
Maximum Load, P_z : 6,996 lbs
 Poisson's Ratio, v_{xz} : 0.1274

Measured Specimen Dimensions:

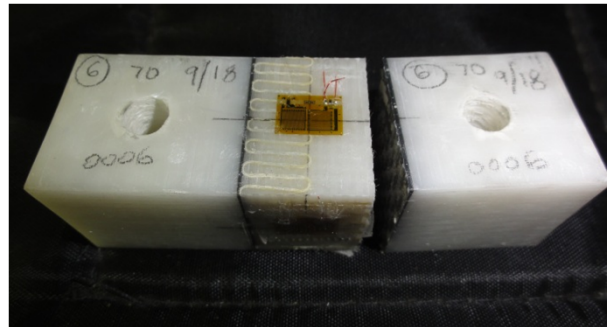
Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 40% Max Load: 2,798 lbs
 10% Max Load: 700 lbs

PICTURE OF SPECIMEN PRE-TEST

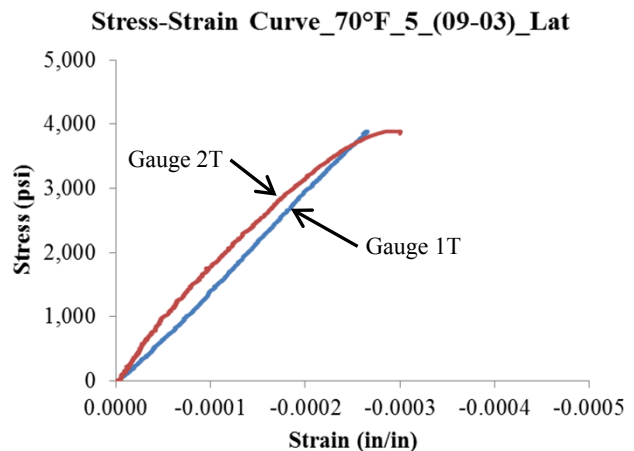
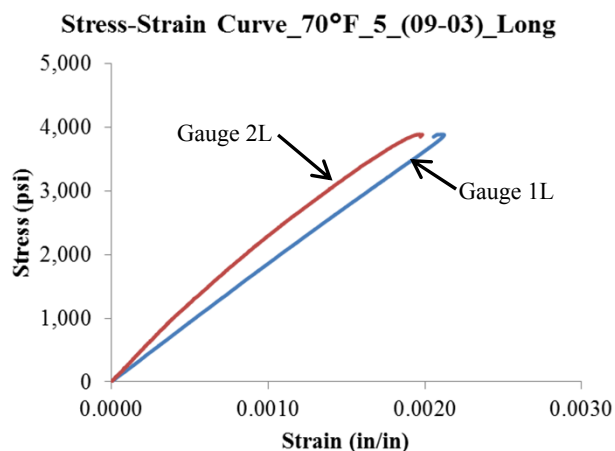


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | Gauge | Strain @ 40% Max Load, (in/in) | Strain @ 10% Max Load, (in/in) | |
| 1L | 0.001521 | 0.000373 | 1T | -0.000190 | -0.000054 | 0.1185 |
| 2L | 0.001264 | 0.000270 | 2T | -0.000171 | -0.000035 | 0.1362 |
| Average | | | | | | 0.1274 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 10% and 40% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

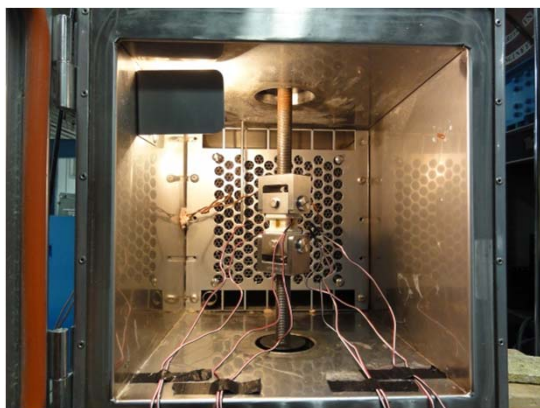
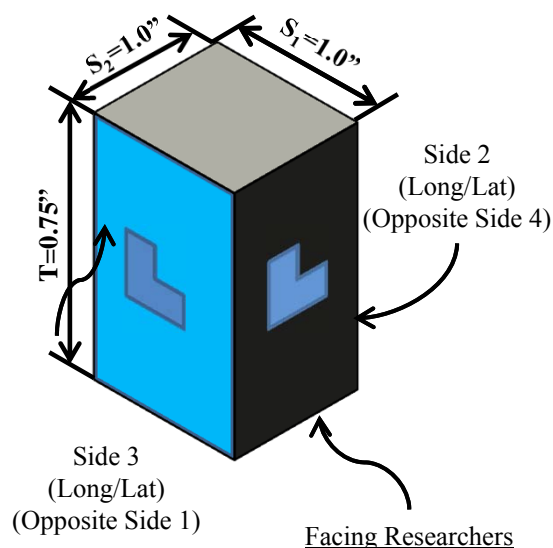
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT3-OP-140-FY09**
 Material: **3D Hybrid Panels, S2-Glass Warp with Aramid Z-Fibers**
 Nominal Temperature: **140°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.0750**
 Maximum Load, P_z : **5,388 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT3-OP-1-140-FY09 | 5,346 | 0.0764 | Bondline |
| 2 | MAT3-OP-2-140-FY09 | 5,368 | 0.0904 | Bondline |
| 3 | MAT3-OP-3-140-FY09 | 5,389 | 0.0746 | Bondline |
| 4 | MAT3-OP-4-140-FY09 | 5,411 | 0.0740 | Bondline |
| 5 | MAT3-OP-5-140-FY09 | 5,427 | 0.0594 | Bondline |
| Average | | 5,388 | 0.0750 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The blocks nominal dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference F-140 thru F-144 for individual specimen data.
- 2) 7 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-01-140-FY09**
 Test Date: 8/21/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

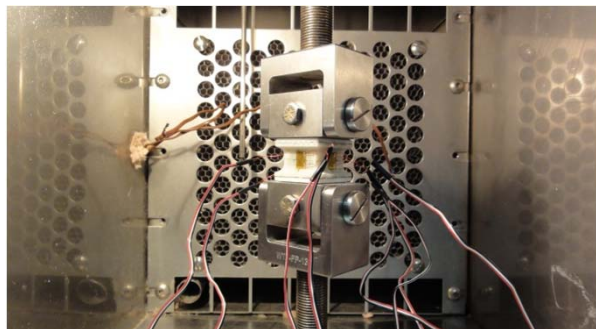
Maximum Load, P_z : 5,346 lbs
 Poisson's Ratio, v_{xz} : 0.0764

Measured Specimen Dimensions:

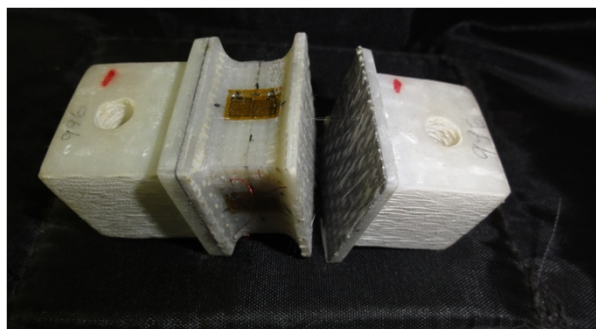
Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.996 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 20% Max Load: 1,069 lbs
 5% Max Load: 267 lbs

PICTURE OF SPECIMEN PRE-TEST



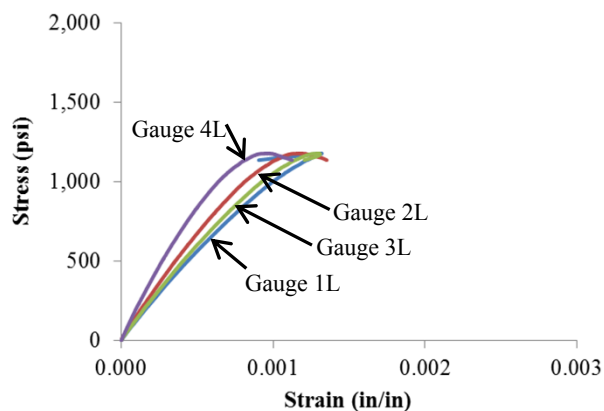
PICTURE OF SPECIMEN POST-TEST



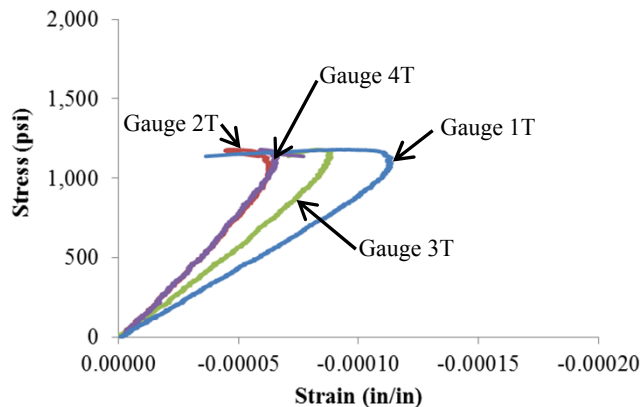
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | |
|--------------------|--------------------------|-------------------------|---------------|--------------------------|-------------------------|-----------------|
| Gauge | Strain @ 20% Max Load | Strain @ 5% Max Load | Gauge | Strain @ 20% Max Load | Strain @ 5% Max Load | Poisson's Ratio |
| | (in/in) | (in/in) | | (in/in) | (in/in) | v_{xz} |
| 1L | 0.001108 | 0.000223 | 1T | -0.000113 | -0.000032 | 0.0919 |
| 2L | 0.000909 | 0.000182 | 2T | -0.000063 | -0.000019 | 0.0601 |
| 3L | 0.001031 | 0.000208 | 3T | -0.000086 | -0.000024 | 0.0748 |
| 4L | 0.000721 | 0.000136 | 4T | -0.000065 | -0.000019 | 0.0788 |
| Average | | | | | | 0.0764 |

Stress-Strain Curve_140°F_1_(09-03)_Long



Stress-Strain Curve_140°F_1_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges on all sides.
- *Poisson's Ratio was calculated using strain at 5% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-02-140-FY09**
 Test Date: 8/21/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

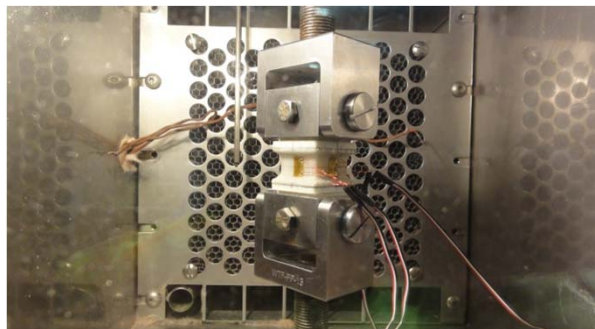
Maximum Load, P_z : 5,368 lbs
 Poisson's Ratio, v_{xz} : 0.0904

Measured Specimen Dimensions:

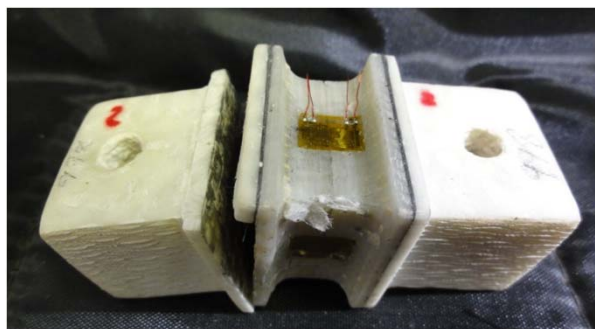
Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 20% Max Load: 1,074 lbs
 5% Max Load: 268 lbs

PICTURE OF SPECIMEN PRE-TEST



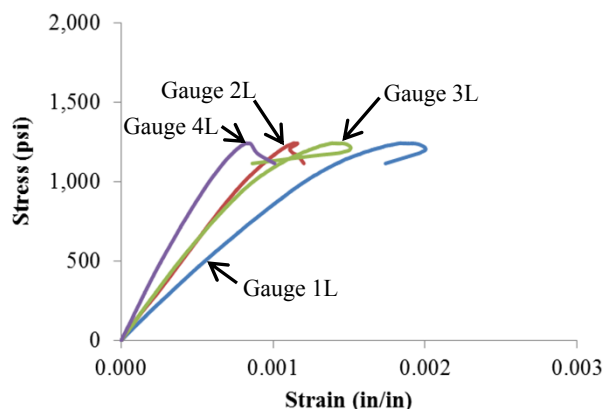
PICTURE OF SPECIMEN POST-TEST



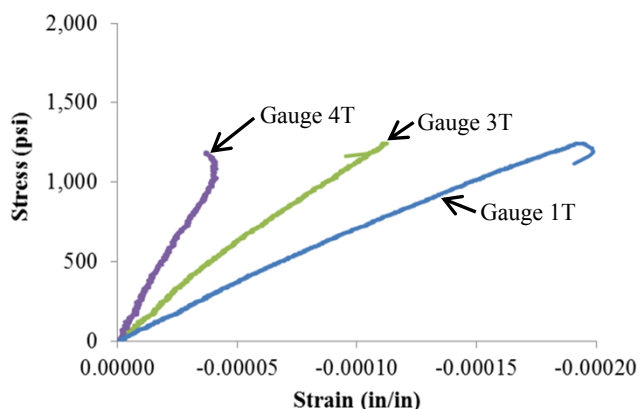
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | |
|--------------------|--------------------------|-------------------------|---------------|--------------------------|-------------------------|-----------------|
| Gauge | Strain @ 20% Max Load | Strain @ 5% Max Load | Gauge | Strain @ 20% Max Load | Strain @ 5% Max Load | Poisson's Ratio |
| | (in/in) | (in/in) | | (in/in) | (in/in) | v_{xz} |
| 1L | 0.001337 | 0.000286 | 1T | -0.000160 | -0.000037 | 0.1172 |
| 2L | 0.000890 | 0.000213 | 2T | Lost Gauge | | |
| 3L | 0.000978 | 0.000202 | 3T | -0.000094 | -0.000021 | 0.0942 |
| 4L | 0.000638 | 0.000139 | 4T | -0.000040 | -0.000010 | 0.0600 |
| Average | | | | | | 0.0904 |

Stress-Strain Curve_140°F_2_(09-03)_Long



Stress-Strain Curve_140°F_2_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges on all sides.
- *Poisson's Ratio was calculated using strain at 5% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-03-70-FY09**
 Test Date: 9/17/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

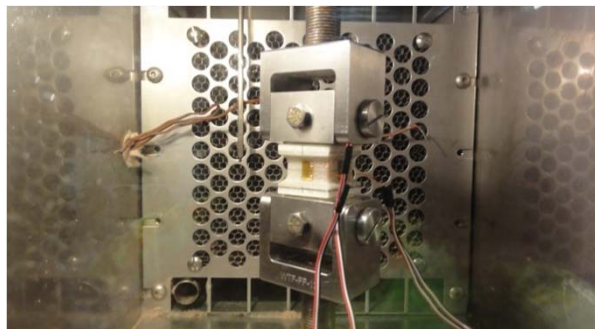
Maximum Load, P_z : 5,389 lbs
 Poisson's Ratio, v_{xz} : 0.0746

Measured Specimen Dimensions:

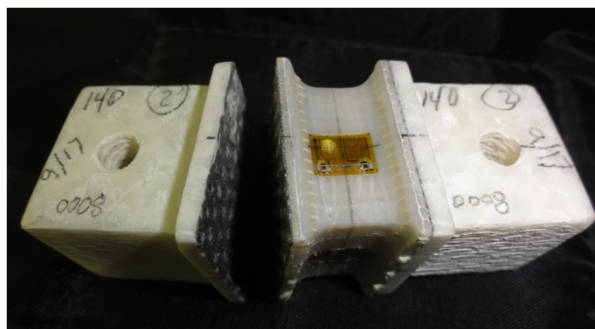
Thickness: 0.750 in
 Side 1: 1.003 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 20% Max Load: 1,078 lbs
 5% Max Load: 269 lbs

PICTURE OF SPECIMEN PRE-TEST



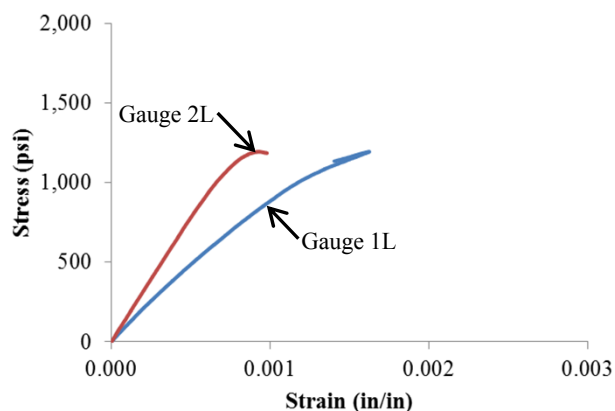
PICTURE OF SPECIMEN POST-TEST



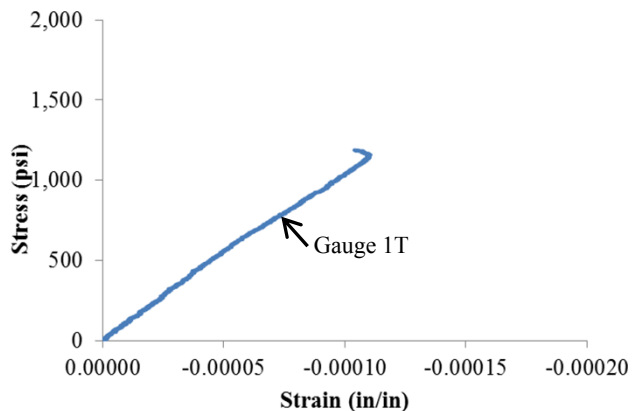
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|-------------------------------|----------------|--------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | |
| 1L | 0.001321 | 0.000263 | 1T | -0.000104 | -0.000025 | 0.0746 |
| 2L | 0.000728 | 0.000169 | 2T | Lost Gauge | | |
| Average | | | | | | 0.0746 |

Stress-Strain Curve_140°F_3_(09-03)_Long



Stress-Strain Curve_140°F_3_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 5% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-04-70-FY09**
 Test Date: 9/17/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

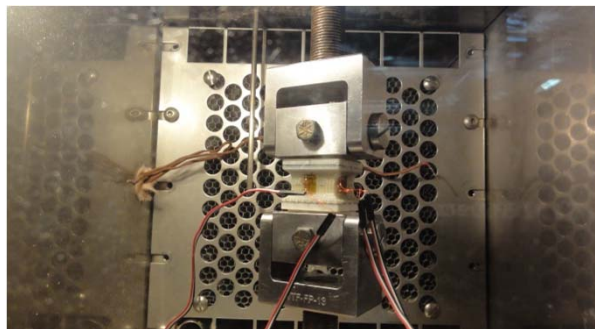
Maximum Load, P_z : 5,411 lbs
 Poisson's Ratio, v_{xz} : 0.0740

Measured Specimen Dimensions:

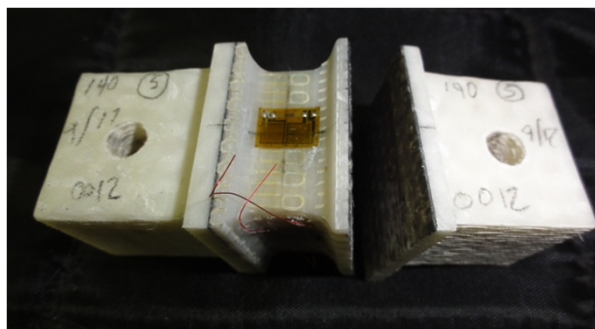
Thickness: 0.750 in
 Side 1: 1.004 in
 Side 2: 1.003 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 20% Max Load: 1,082 lbs
 5% Max Load: 271 lbs

PICTURE OF SPECIMEN PRE-TEST



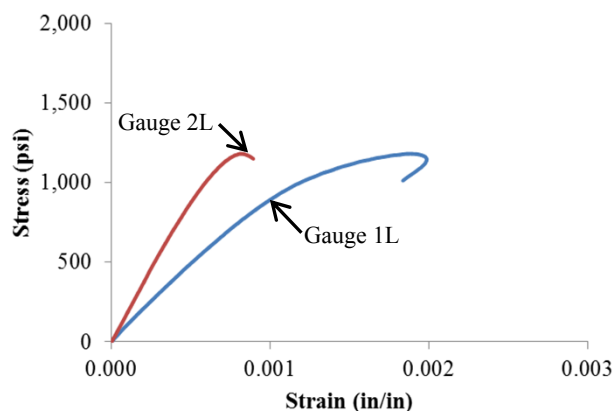
PICTURE OF SPECIMEN POST-TEST



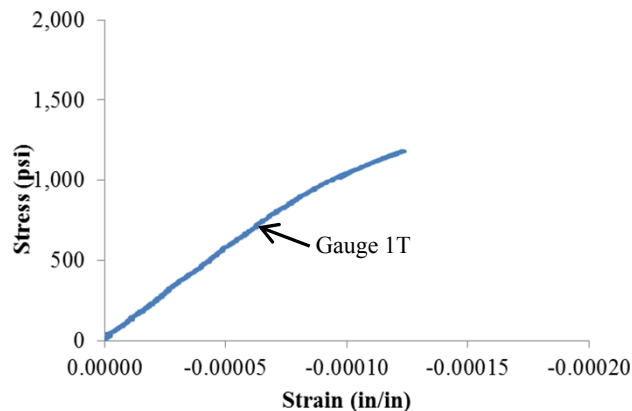
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|-------------------------------|----------------|--------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | |
| 1L | 0.001381 | 0.000262 | 1T | -0.000106 | -0.000023 | 0.0740 |
| 2L | 0.000657 | 0.000147 | 2T | Lost Gauge | | |
| Average | | | | | | 0.0740 |

Stress-Strain Curve_140°F_4_(09-03)_Long



Stress-Strain Curve_140°F_4_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 5% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT3-OP-05-70-FY09**
 Test Date: 9/18/2012
 Specimen Received: 8/6/2012
 Properties Measured: v_{xz}

Average Material Properties:

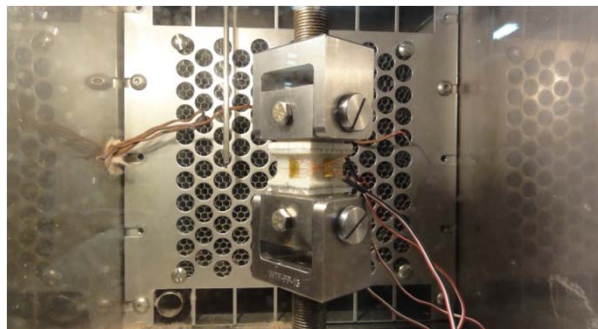
Maximum Load, P_z : 5,427 lbs
 Poisson's Ratio, v_{xz} : 0.0594

Measured Specimen Dimensions:

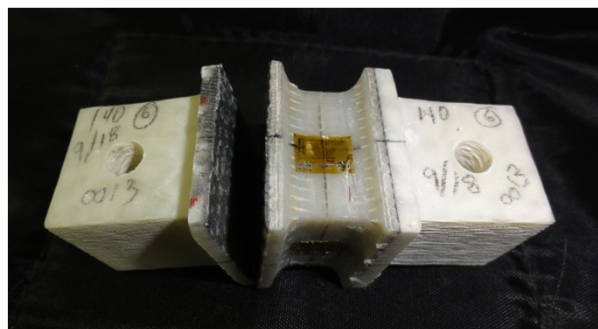
Thickness: 0.750 in
 Side 1: 1.006 in
 Side 2: 1.004 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 20% Max Load: 1,085 lbs
 5% Max Load: 271 lbs

PICTURE OF SPECIMEN PRE-TEST



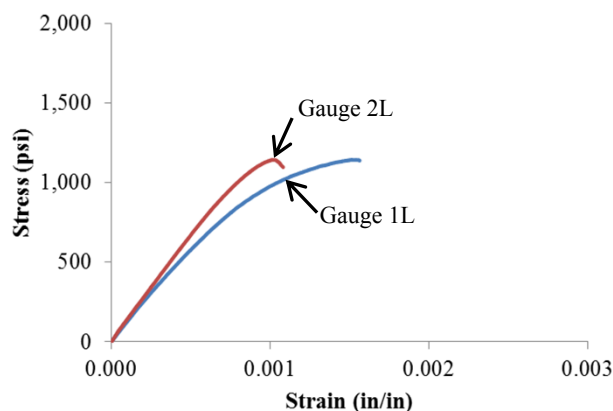
PICTURE OF SPECIMEN POST-TEST



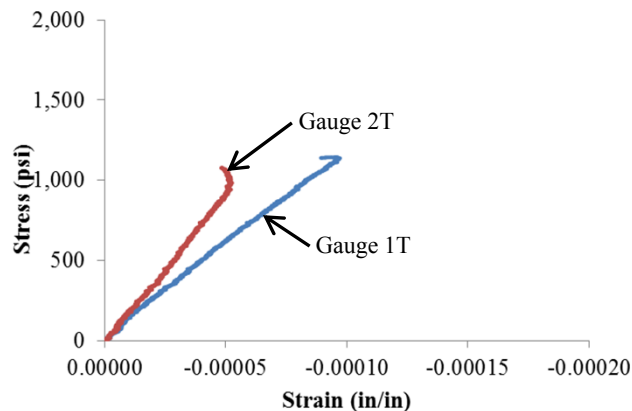
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|-------------------------------|----------------|--------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | Gauge | Strain @ 20% Max Load, (in/in) | Strain @ 5% Max Load, (in/in) | |
| 1L | 0.001227 | 0.000216 | 1T | -0.000091 | -0.000020 | 0.0702 |
| 2L | 0.000881 | 0.000194 | 2T | -0.000049 | -0.000016 | 0.0486 |
| Average | | | | | | 0.0594 |

Stress-Strain Curve_140°F_5_(09-03)_Long



Stress-Strain Curve_140°F_5_(09-03)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 5% and 20% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX G

MATERIAL 4-FY09 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-TX-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: N40°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 23,346 lbs
 Tensile Strength, ST_x : 53,827 psi
 Tensile Modulus, E_x : 2,592,766 psi
 Ultimate Strain, ϵ_x : 0.0208 in/in
 Poisson's Ratio, ν_{xy} : 0.2568

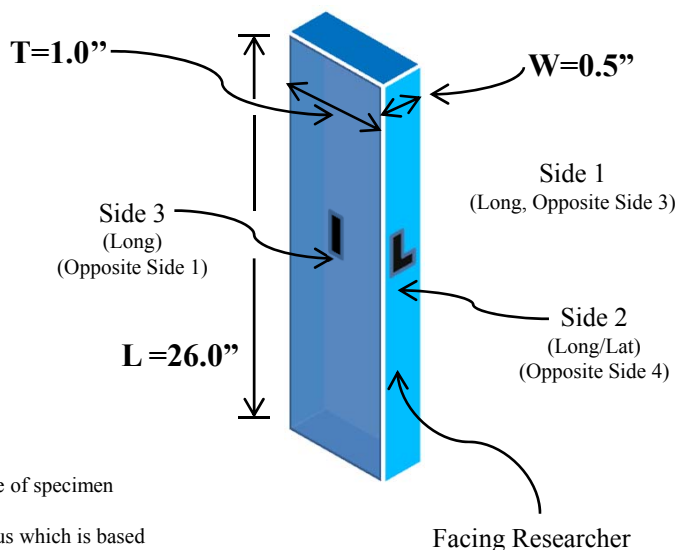
| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT4-TX-1-N40-FY09 | 22,454 | 51,955 | 2,656,725 | 0.0196 | 0.2505 | DGM |
| 2 | MAT4-TX-2-N40-FY09 | 22,574 | 54,867 | 2,632,858 | 0.0208 | 0.2879 | DGM |
| 3 | MAT4-TX-3-N40-FY09 | 23,798 | 54,783 | 2,668,429 | 0.0205 | 0.2555 | DGM |
| 4 | MAT4-TX-4-N40-FY09 | 23,220 | 53,322 | 2,511,767 | 0.0212 | 0.2350 | DGM |
| 5 | MAT4-TX-5-N40-FY09 | 24,683 | 54,210 | 2,494,053 | 0.0217 | 0.2549 | DGM |
| Average | | 23,346 | 53,827 | 2,592,766 | 0.0208 | 0.2568 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See G-2 to G-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-1-N40-FY09**
 Test Date: 3/17/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

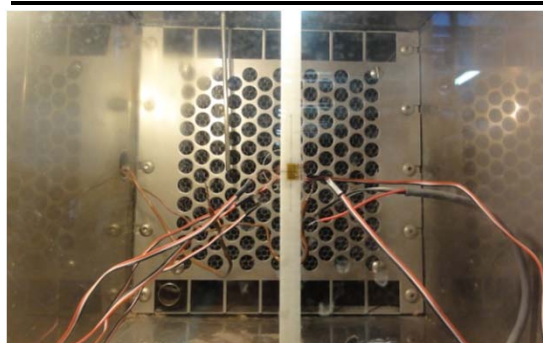
Average Material Properties:

Ultimate Load, P_x : 22,454 lbs
 Tensile Strength, ST_x : 51,955 psi
 Tensile Modulus, E_x : 2,656,725 psi
 Ultimate Strain, ϵ_x : 0.0196 in/in
 Poisson's Ratio, ν_{xy} : 0.2505

Measured Specimen Dimensions:

Width, W: 0.4802 in
 Thickness, H: 0.9000 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,491 lbs
 50% Max Load: 11,227 lbs

PICTURE OF SPECIMEN PRE-TEST



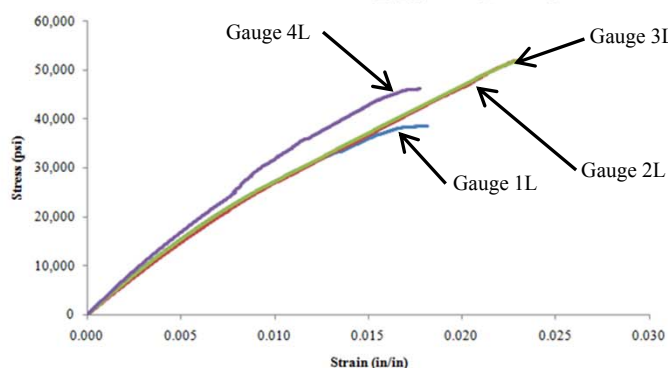
PICTURE OF SPECIMEN POST-TEST



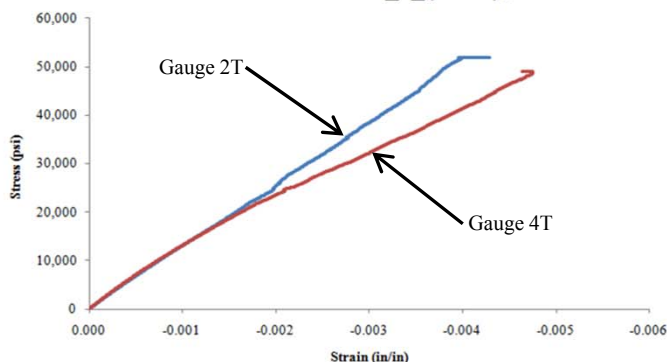
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0094 | 0.0032 | 2,519,206 | | | | |
| 2L | 0.0096 | 0.0034 | 2,545,362 | 2T | -0.0020 | -0.0008 | 0.2060 |
| 3L | 0.0094 | 0.0032 | 2,541,592 | | | | |
| 4L | 0.0081 | 0.0029 | 3,020,741 | 4T | -0.0023 | -0.0008 | 0.2950 |
| Average | | | 2,656,725 | | | | 0.2505 |

Stress-Strain Curve N40_1_(09-04), Long.



Stress-Strain Curve N40_1_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-2-N40-FY09**
 Test Date: 3/17/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

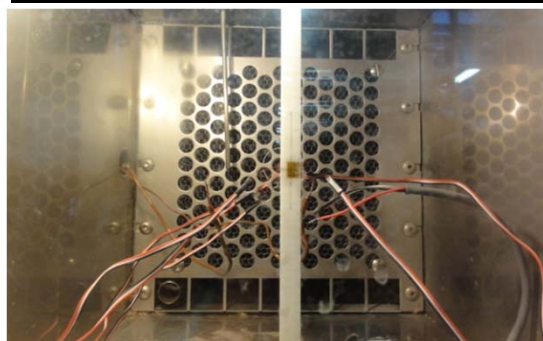
Average Material Properties:

Ultimate Load, P_x : 22,574 lbs
 Tensile Strength, ST_x : 54,867 psi
 Tensile Modulus, E_x : 2,632,858 psi
 Ultimate Strain, ϵ_x : 0.0208 in/in
 Poisson's Ratio, ν_{xy} : 0.2879

Measured Specimen Dimensions:

Width, W: 0.4627 in
 Thickness, H: 0.8892 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,515 lbs
 50% Max Load: 11,287 lbs

PICTURE OF SPECIMEN PRE-TEST



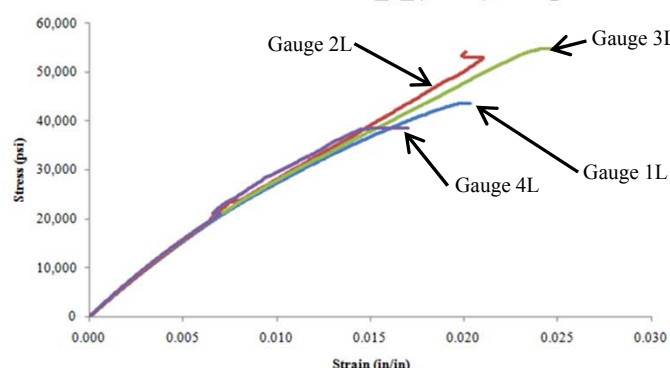
PICTURE OF SPECIMEN POST-TEST



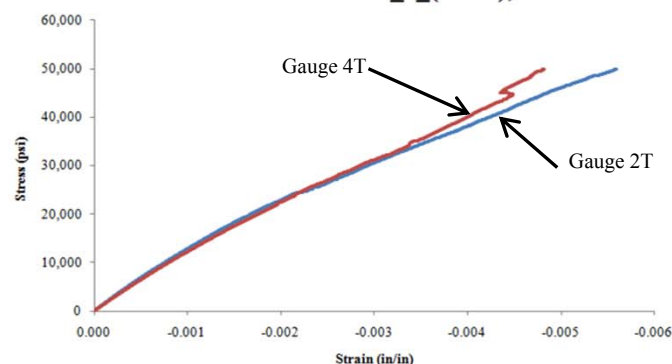
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0101 | 0.0035 | 2,491,417 | | | | |
| 2L | 0.0097 | 0.0034 | 2,628,745 | 2T | -0.0026 | -0.0008 | 0.2844 |
| 3L | 0.0098 | 0.0033 | 2,536,043 | | | | |
| 4L | 0.0090 | 0.0033 | 2,875,228 | 4T | -0.0026 | -0.0009 | 0.2913 |
| Average | | | 2,632,858 | | | | 0.2879 |

Stress-Strain Curve N40_2_(09-04), Long.



Stress-Strain Curve N40_2_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-3-N40-FY09**
 Test Date: 4/12/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

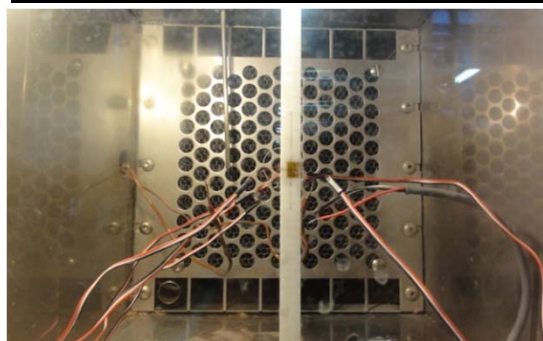
Average Material Properties:

Ultimate Load, P_x : 23,798 lbs
 Tensile Strength, ST_x : 54,783 psi
 Tensile Modulus, E_x : 2,668,429 psi
 Ultimate Strain, ϵ_x : 0.0205 in/in
 Poisson's Ratio, ν_{xy} : 0.2555

Measured Specimen Dimensions:

Width, W: 0.4875 in
 Thickness, H: 0.8911 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,760 lbs
 50% Max Load: 11,899 lbs

PICTURE OF SPECIMEN PRE-TEST



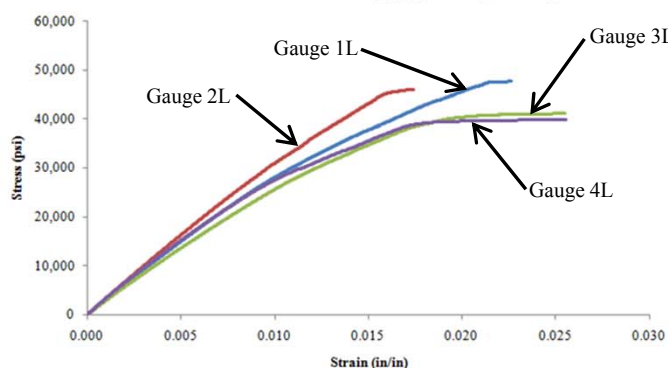
PICTURE OF SPECIMEN POST-TEST



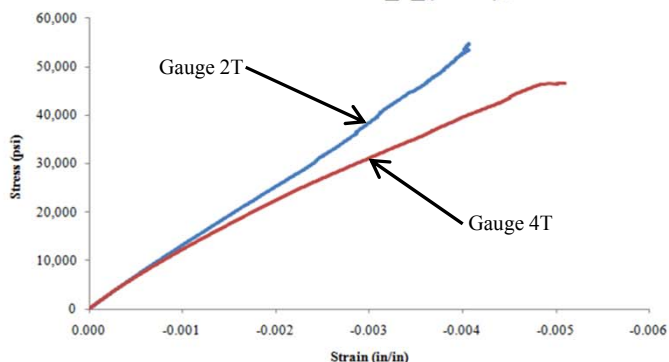
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0097 | 0.0036 | 2,689,071 | | | | |
| 2L | 0.0087 | 0.0033 | 3,045,230 | 2T | -0.0022 | -0.0008 | 0.2514 |
| 3L | 0.0108 | 0.0040 | 2,389,062 | | | | |
| 4L | 0.0099 | 0.0035 | 2,550,353 | 4T | -0.0025 | -0.0009 | 0.2596 |
| Average | | | 2,668,429 | | | | 0.2555 |

Stress-Strain Curve N40_3_(09-04), Long.



Stress-Strain Curve N40_3_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-4-N40-FY09**
 Test Date: 4/12/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

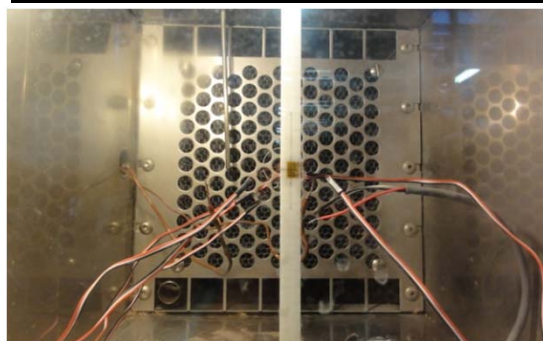
Average Material Properties:

Ultimate Load, P_x : 23,220 lbs
 Tensile Strength, ST_x : 53,322 psi
 Tensile Modulus, E_x : 2,511,767 psi
 Ultimate Strain, ϵ_x : 0.0212 in/in
 Poisson's Ratio, ν_{xy} : 0.2350

Measured Specimen Dimensions:

Width, W: 0.4870 in
 Thickness, H: 0.8942 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,644 lbs
 50% Max Load: 11,610 lbs

PICTURE OF SPECIMEN PRE-TEST



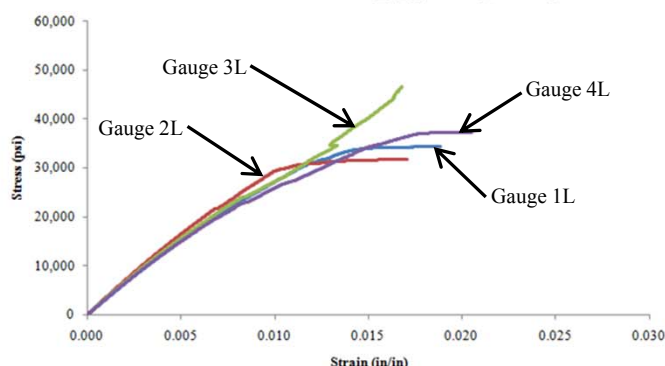
PICTURE OF SPECIMEN POST-TEST



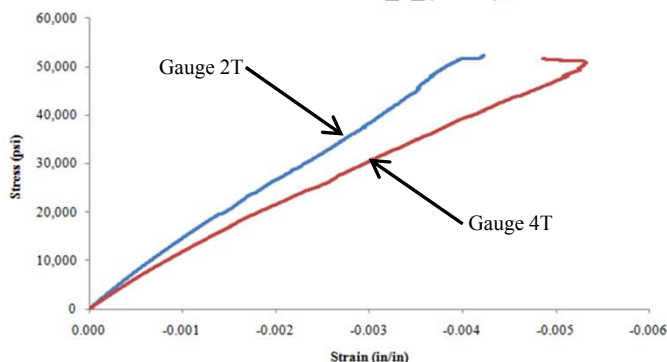
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0098 | 0.0034 | 2,511,725 | | | | |
| 2L | 0.0089 | 0.0031 | 2,764,436 | 2T | -0.0020 | -0.0007 | 0.2250 |
| 3L | 0.0097 | 0.0033 | 2,484,794 | | | | |
| 4L | 0.0104 | 0.0034 | 2,286,114 | 4T | -0.0026 | -0.0009 | 0.2450 |
| Average | | | 2,511,767 | | | | 0.2350 |

Stress-Strain Curve N40_4_(09-04), Long.



Stress-Strain Curve N40_4_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-5-N40-FY09**
 Test Date: 4/13/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

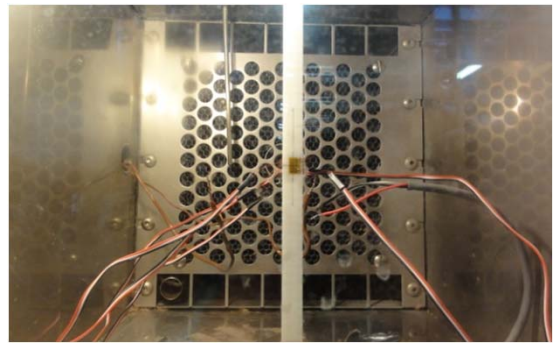
Average Material Properties:

Ultimate Load, P_x : 24,683 lbs
 Tensile Strength, ST_x : 54,210 psi
 Tensile Modulus, E_x : 2,494,053 psi
 Ultimate Strain, ϵ_x : 0.0217 in/in
 Poisson's Ratio, ν_{xy} : 0.2549

Measured Specimen Dimensions:

Width, W: 0.5100 in
 Thickness, H: 0.8928 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,937 lbs
 50% Max Load: 12,342 lbs

PICTURE OF SPECIMEN PRE-TEST



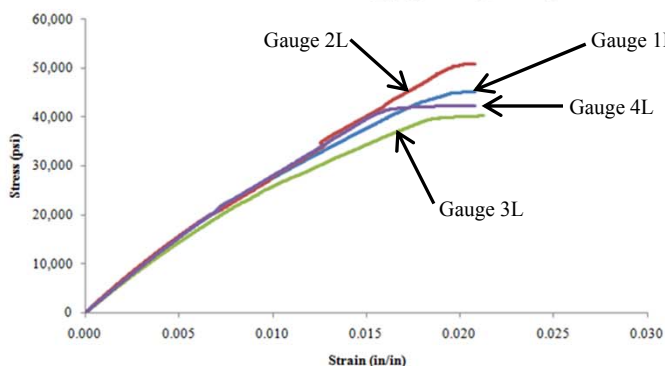
PICTURE OF SPECIMEN POST-TEST



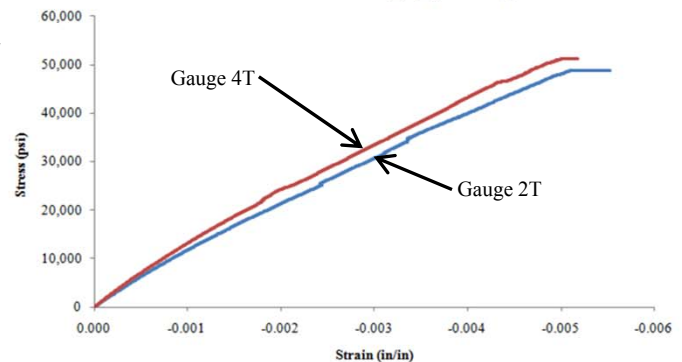
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0098 | 0.0034 | 2,532,245 | | | | |
| 2L | 0.0098 | 0.0033 | 2,507,071 | 2T | -0.0026 | -0.0009 | 0.2605 |
| 3L | 0.0107 | 0.0037 | 2,295,577 | | | | |
| 4L | 0.0096 | 0.0034 | 2,641,319 | 4T | -0.0023 | -0.0008 | 0.2493 |
| Average | | | 2,494,053 | | | | 0.2549 |

Stress-Strain Curve N40_5_(09-04), Long.



Stress-Strain Curve N40_5_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-TX-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: ST_x , E_x , ν_{xy}

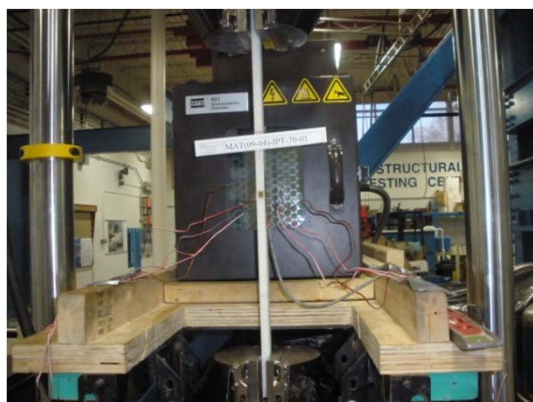
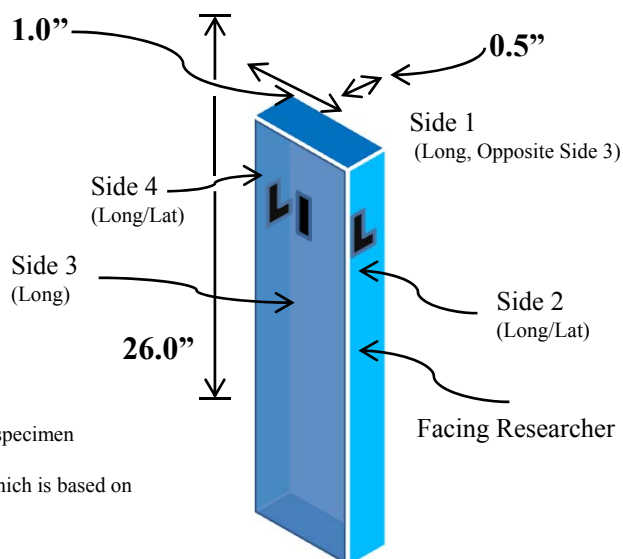
Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 22,613 | lbs |
| Tensile Strength, ST_x : | 49,131 | psi |
| Tensile Modulus, E_x : | 2,328,807 | psi |
| Ultimate Strain, ϵ_x : | 0.0211 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2184 | |

| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|-------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT4-TX-1-70-FY09 | 23,104 | 50,791 | 2,390,508 | 0.0212 | 0.2143 | DGM |
| 2 | MAT4-TX-2-70-FY09 | 24,726 | 50,848 | 2,274,902 | 0.0224 | 0.2058 | DGM |
| 3 | MAT4-TX-3-70-FY09 | 21,304 | 47,558 | 2,341,371 | 0.0203 | 0.2473 | DGM |
| 4 | MAT4-TX-4-70-FY09 | 21,974 | 48,718 | 2,451,907 | 0.0199 | 0.2194 | DGM |
| 5 | MAT4-TX-5-70-FY09 | 21,954 | 47,742 | 2,185,347 | 0.0218 | 0.2051 | DGM |
| Average | | 22,613 | 49,131 | 2,328,807 | 0.0211 | 0.2184 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See G-8 to G-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-1-70-FY09**
 Test Date: 3/01/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

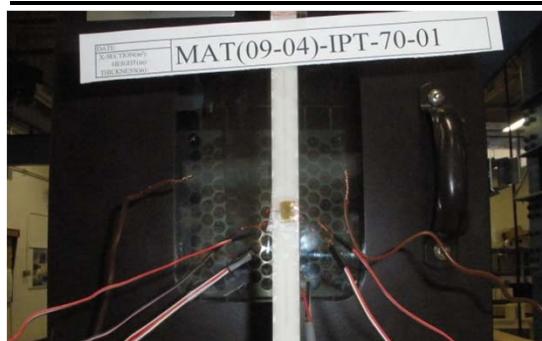
Average Material Properties:

Ultimate Load, P_x : 23,104 lbs
 Tensile Strength, ST_x : 50,791 psi
 Tensile Modulus, E_x : 2,390,508 psi
 Ultimate Strain, ϵ_x : 0.0212 in/in
 Poisson's Ratio, ν_{xy} : 0.2143

Measured Specimen Dimensions:

Width, W: 0.5110 in
 Thickness, H: 0.8902 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,621 lbs
 50% Max Load: 11,552 lbs

PICTURE OF SPECIMEN PRE-TEST



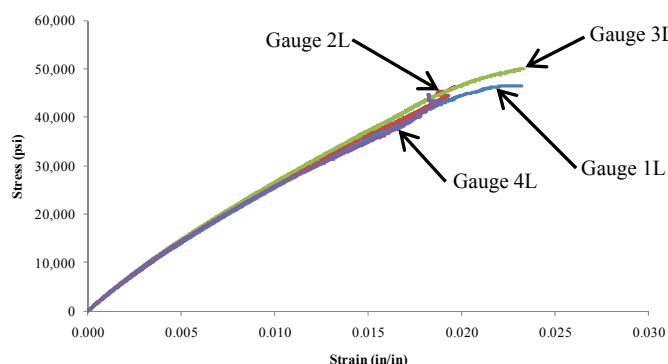
PICTURE OF SPECIMEN POST-TEST



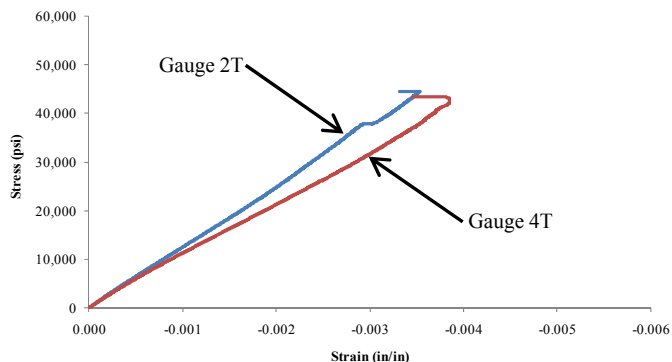
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0099 | 0.0035 | 2,348,968 | | | | |
| 2L | 0.0097 | 0.0033 | 2,403,830 | 2T | -0.0020 | -0.0008 | 0.1958 |
| 3L | 0.0095 | 0.0033 | 2,464,208 | | | | |
| 4L | 0.0098 | 0.0033 | 2,345,028 | 4T | -0.0024 | -0.0009 | 0.2328 |
| Average | | | 2,390,508 | | | | 0.2143 |

Stress-Strain Curve 70_1, Long.



Stress-Strain Curve 70_1, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-2-70-FY09**
 Test Date: 3/01/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , v_{xy}

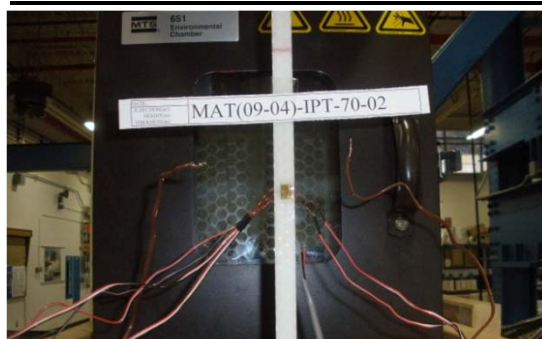
Average Material Properties:

Ultimate Load, P_x : 24,726 lbs
 Tensile Strength, ST_x : 50,848 psi
 Tensile Modulus, E_x : 2,274,902 psi
 Ultimate Strain, ϵ_x : 0.0224 in/in
 Poisson's Ratio, v_{xy} : 0.2058

Measured Specimen Dimensions:

Width, W: 0.5423 in
 Thickness, H: 0.8967 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,945 lbs
 50% Max Load: 12,363 lbs

PICTURE OF SPECIMEN PRE-TEST



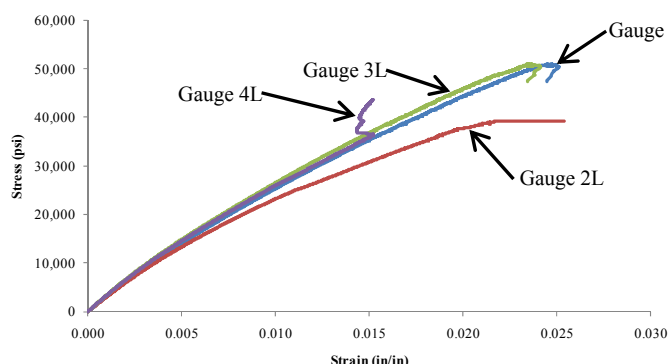
PICTURE OF SPECIMEN POST-TEST



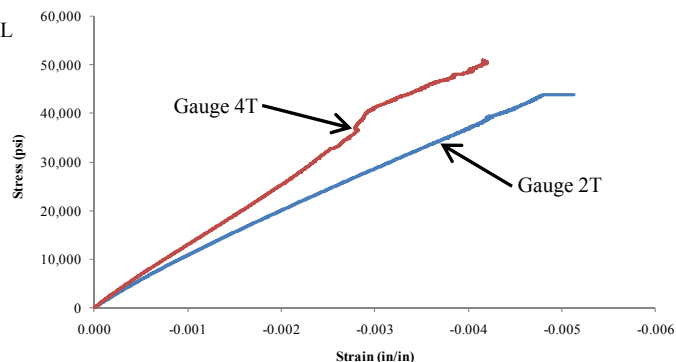
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0100 | 0.0035 | 2,325,237 | | | | |
| 2L | 0.0114 | 0.0036 | 1,973,350 | 2T | -0.0026 | -0.0009 | 0.2184 |
| 3L | 0.0095 | 0.0032 | 2,429,156 | | | | |
| 4L | 0.0097 | 0.0033 | 2,371,866 | 4T | -0.0020 | -0.0008 | 0.1933 |
| Average | | | 2,274,902 | | | | 0.2058 |

Stress-Strain Curve 70_2, Long.



Stress-Strain Curve 70_2, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-3-70-FY09**
 Test Date: 3/11/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

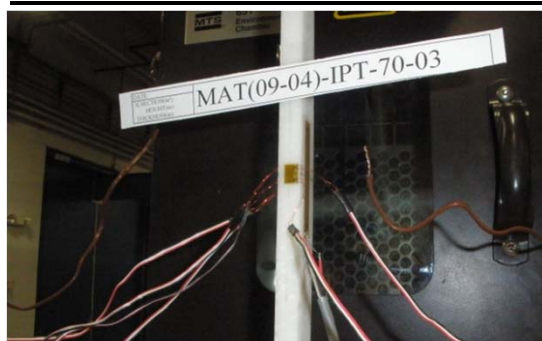
Average Material Properties:

Ultimate Load, P_x : 21,304 lbs
 Tensile Strength, ST_x : 47,558 psi
 Tensile Modulus, E_x : 2,341,371 psi
 Ultimate Strain, ϵ_x : 0.0203 in/in
 Poisson's Ratio, ν_{xy} : 0.2473

Measured Specimen Dimensions:

Width, W: 0.4941 in
 Thickness, H: 0.9066 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,261 lbs
 50% Max Load: 10,652 lbs

PICTURE OF SPECIMEN PRE-TEST



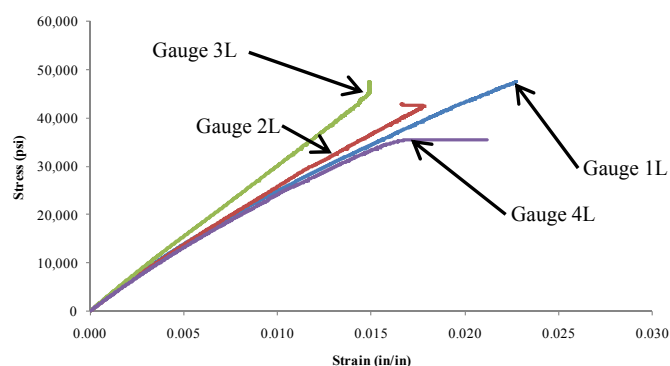
PICTURE OF SPECIMEN POST-TEST



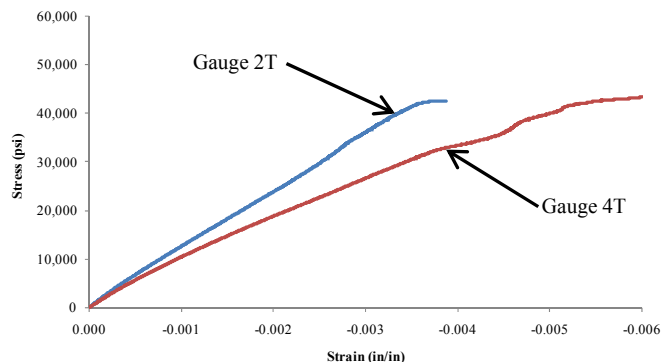
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0095 | 0.0033 | 2,302,629 | | | | |
| 2L | 0.0092 | 0.0034 | 2,460,611 | 2T | -0.0020 | -0.0007 | 0.2181 |
| 3L | Malfunctioning Gauge | | | | | | |
| 4L | 0.0098 | 0.0035 | 2,260,872 | 4T | -0.0026 | -0.0009 | 0.2765 |
| Average | | | 2,341,371 | | | | 0.2473 |

Stress-Strain Curve 70_3, Long.



Stress-Strain Curve 70_3, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-4-70-FY09**
 Test Date: 3/02/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , v_{xy}

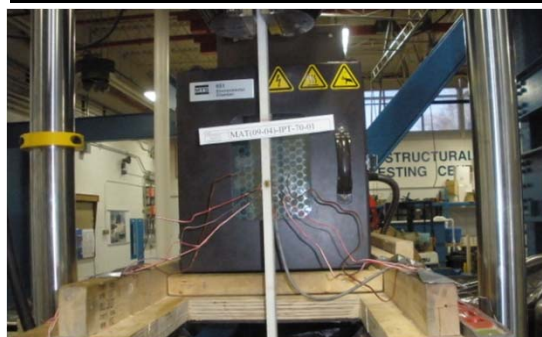
Average Material Properties:

Ultimate Load, P_x : 21,974 lbs
 Tensile Strength, ST_x : 48,718 psi
 Tensile Modulus, E_x : 2,451,907 psi
 Ultimate Strain, ϵ_x : 0.0199 in/in
 Poisson's Ratio, v_{xy} : 0.2194

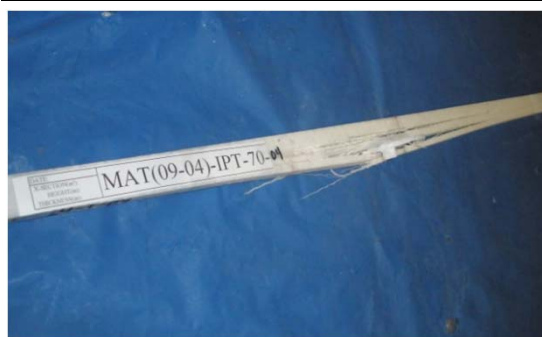
Measured Specimen Dimensions:

Width, W: 0.5035 in
 Thickness, H: 0.8958 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,395 lbs
 50% Max Load: 10,987 lbs

PICTURE OF SPECIMEN PRE-TEST



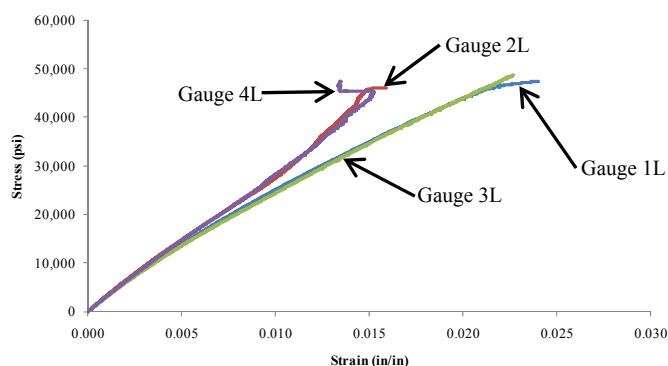
PICTURE OF SPECIMEN POST-TEST



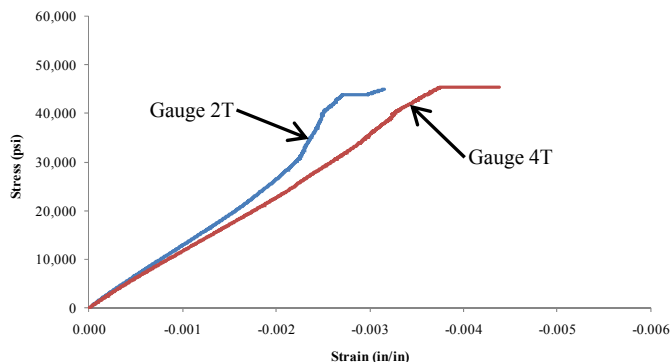
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0096 | 0.0033 | 2,318,701 | | | | |
| 2L | 0.0088 | 0.0031 | 2,581,294 | 2T | -0.0019 | -0.0007 | 0.1977 |
| 3L | 0.0100 | 0.0034 | 2,232,800 | | | | |
| 4L | 0.0087 | 0.0032 | 2,674,832 | 4T | -0.0021 | -0.0008 | 0.2412 |
| Average | | | 2,451,907 | | | | 0.2194 |

Stress-Strain Curve 70_4, Long.



Stress-Strain Curve 70_4, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-5-70-FY09**
 Test Date: 3/02/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

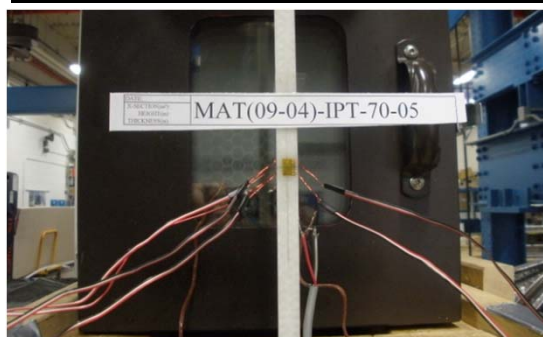
Average Material Properties:

Ultimate Load, P_x : 21,954 lbs
 Tensile Strength, ST_x : 47,742 psi
 Tensile Modulus, E_x : 2,185,347 psi
 Ultimate Strain, ϵ_x : 0.0218 in/in
 Poisson's Ratio, ν_{xy} : 0.2051

Measured Specimen Dimensions:

Width, W: 0.4951 in
 Thickness, H: 0.8981 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,391 lbs
 50% Max Load: 10,977 lbs

PICTURE OF SPECIMEN PRE-TEST



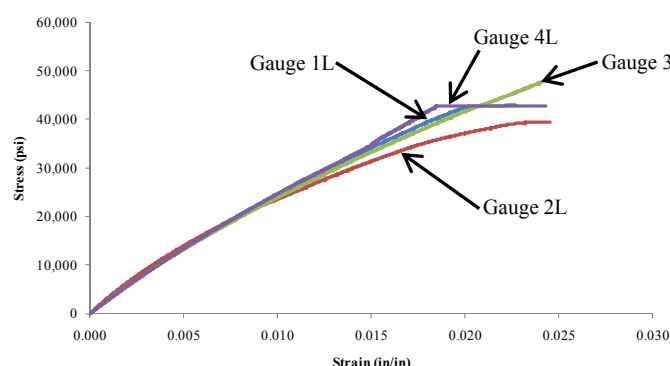
PICTURE OF SPECIMEN POST-TEST



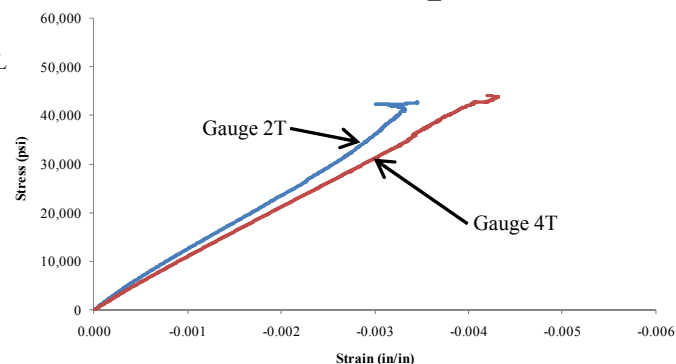
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0101 | 0.0035 | 2,246,952 | | | | |
| 2L | 0.0107 | 0.0033 | 2,001,028 | 2T | -0.0021 | -0.0008 | 0.1822 |
| 3L | 0.0104 | 0.0036 | 2,183,768 | | | | |
| 4L | 0.0100 | 0.0036 | 2,309,641 | 4T | -0.0024 | -0.0009 | 0.2279 |
| Average | | | 2,185,347 | | | | 0.2051 |

Stress-Strain Curve 70_5, Long.



Stress-Strain Curve 70_5, Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-TX-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 19,485 | lbs |
| Tensile Strength, ST_x : | 43,236 | psi |
| Tensile Modulus, E_x : | 2,243,374 | psi |
| Ultimate Strain, ϵ_x : | 0.0193 | in/in |
| Poisson's Ratio, v_{xy} : | 0.2769 | |

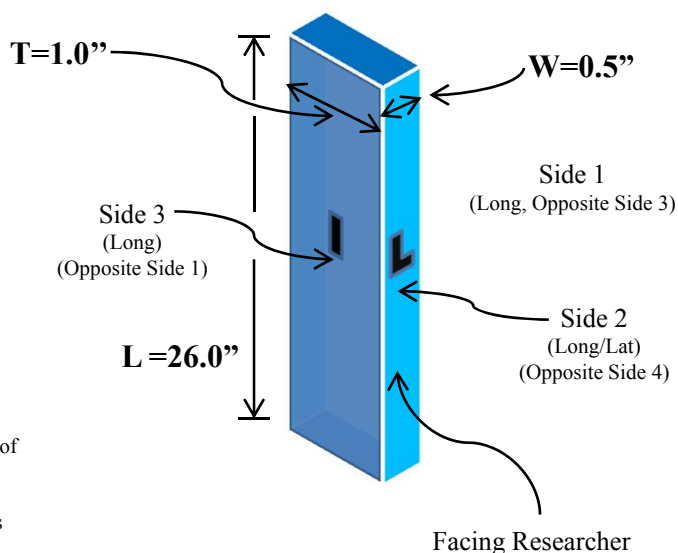
| Sample | Specimen | Max Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, v_{xy} | Failure Mode |
|----------------|--------------------|-----------------------|--------------------------------|------------------------------|---------------------------------------|---------------------------|--------------|
| 1 | MAT4-TX-1-140-FY09 | 19,648 | 41,914 | 2,208,130 | 0.0190 | 0.2739 | DGM |
| 2 | MAT4-TX-2-140-FY09 | 20,445 | 43,965 | 2,198,904 | 0.0200 | 0.2934 | DGM |
| 3 | MAT4-TX-3-140-FY09 | 20,232 | 43,316 | 2,341,277 | 0.0185 | 0.2737 | DGM |
| 4 | MAT4-TX-4-140-FY09 | 18,673 | 42,796 | 2,116,903 | 0.0202 | 0.2784 | DGM |
| 5 | MAT4-TX-5-140-FY09 | 18,430 | 44,188 | 2,351,656 | 0.0188 | 0.2654 | DGM |
| Average | | 19,485 | 43,236 | 2,243,374 | 0.0193 | 0.2769 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) 7 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See G-14 to G-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-1-140-FY09**
 Test Date: 4/14/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

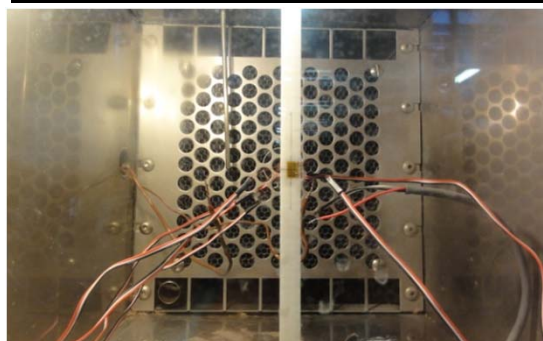
Average Material Properties:

Ultimate Load, P_x : 19,648 lbs
 Tensile Strength, ST_x : 41,914 psi
 Tensile Modulus, E_x : 2,208,130 psi
 Ultimate Strain, ϵ_x : 0.0190 in/in
 Poisson's Ratio, ν_{xy} : 0.2739

Measured Specimen Dimensions:

Width, W: 0.5250 in
 Thickness, H: 0.8929 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 3,930 lbs
 50% Max Load: 9,824 lbs

PICTURE OF SPECIMEN PRE-TEST



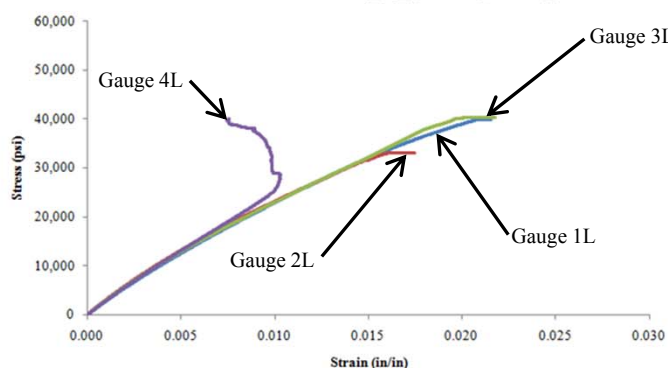
PICTURE OF SPECIMEN POST-TEST



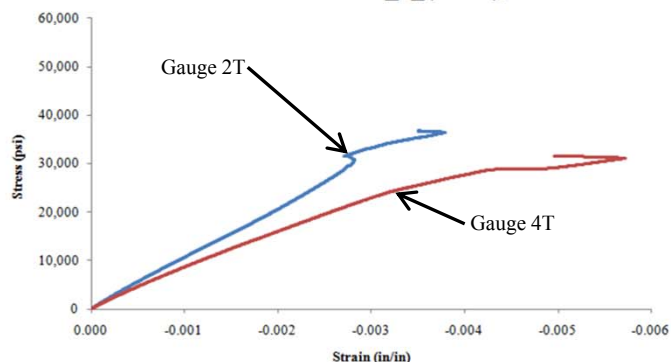
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0090 | 0.0032 | 2,155,767 | | | | |
| 2L | 0.0088 | 0.0030 | 2,152,415 | 2T | -0.0020 | -0.0008 | 0.2169 |
| 3L | 0.0089 | 0.0030 | 2,132,850 | | | | |
| 4L | 0.0083 | 0.0031 | 2,391,489 | 4T | -0.0027 | -0.0010 | 0.3309 |
| Average | | | 2,208,130 | | | | 0.2739 |

Stress-Strain Curve 140_1_(09-04), Long.



Stress-Strain Curve 140_1_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-2-140-FY09**
 Test Date: 4/15/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

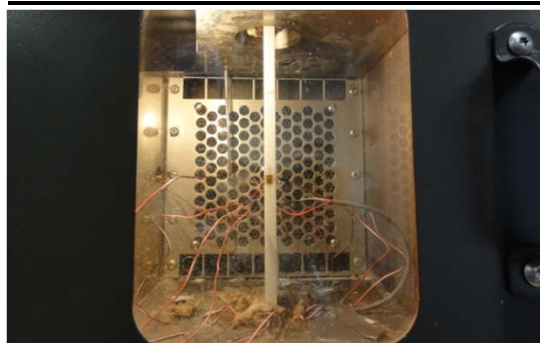
Average Material Properties:

Ultimate Load, P_x : 20,445 lbs
 Tensile Strength, ST_x : 43,965 psi
 Tensile Modulus, E_x : 2,198,904 psi
 Ultimate Strain, ϵ_x : 0.0200 in/in
 Poisson's Ratio, ν_{xy} : 0.2934

Measured Specimen Dimensions:

Width, W: 0.5228 in
 Thickness, H: 0.8895 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,089 lbs
 50% Max Load: 10,223 lbs

PICTURE OF SPECIMEN PRE-TEST



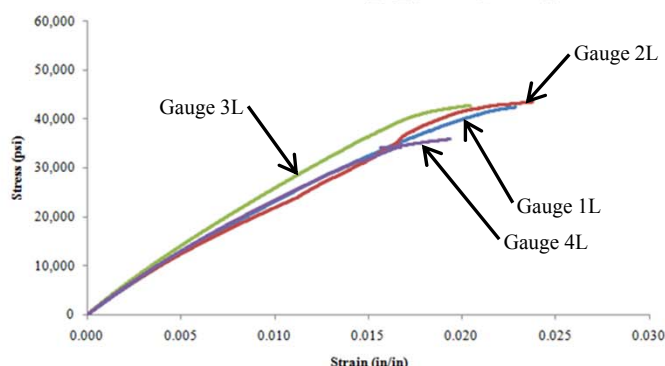
PICTURE OF SPECIMEN POST-TEST



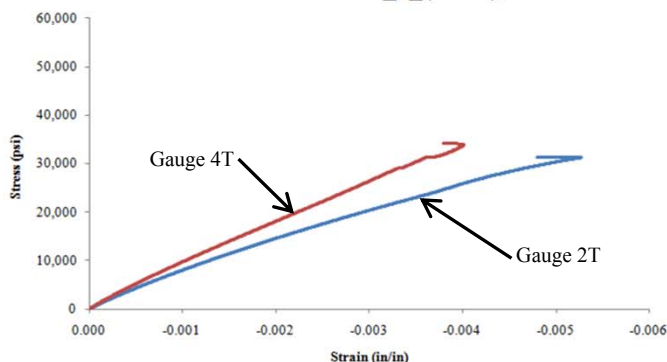
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0094 | 0.0034 | 2,174,581 | | | | |
| 2L | 0.0101 | 0.0033 | 1,962,678 | 2T | -0.0033 | -0.0011 | 0.3257 |
| 3L | 0.0083 | 0.0030 | 2,478,555 | | | | |
| 4L | 0.0093 | 0.0032 | 2,179,804 | 4T | -0.0025 | -0.0009 | 0.2611 |
| Average | | | 2,198,904 | | | | 0.2934 |

Stress-Strain Curve 140_2_(09-04), Long.



Stress-Strain Curve 140_2_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT4-TX-3-140-FY09**
 Test Date: 4/14/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

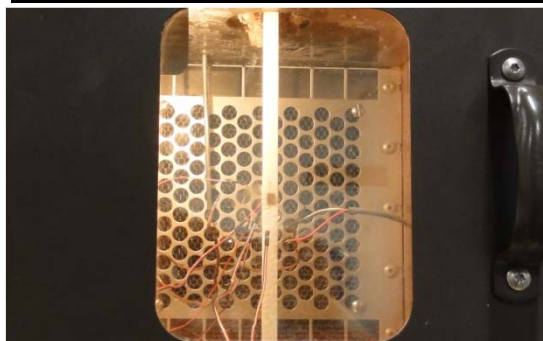
Average Material Properties:

Ultimate Load, P_x : 20,232 lbs
 Tensile Strength, ST_x : 43,316 psi
 Tensile Modulus, E_x : 2,341,277 psi
 Ultimate Strain, ϵ_x : 0.0185 in/in
 Poisson's Ratio, ν_{xy} : 0.2737

Measured Specimen Dimensions:

Width, W: 0.5221 in
 Thickness, H: 0.8946 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 4,046 lbs
 50% Max Load: 10,116 lbs

PICTURE OF SPECIMEN PRE-TEST



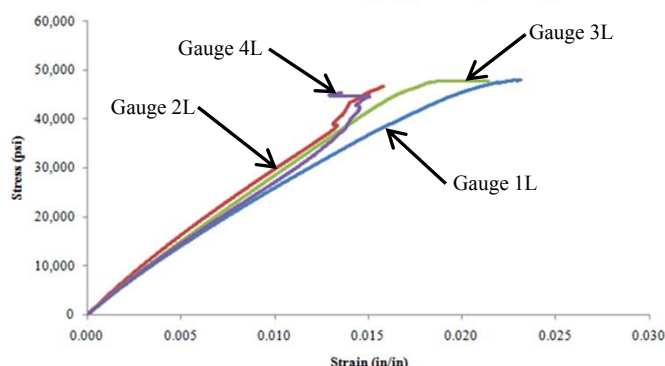
PICTURE OF SPECIMEN POST-TEST



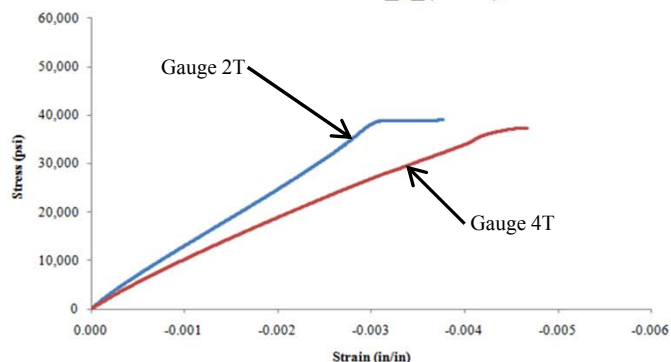
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0094 | 0.0034 | 2,147,613 | | | | |
| 2L | 0.0080 | 0.0029 | 2,527,808 | 2T | -0.0020 | -0.0007 | 0.2447 |
| 3L | 0.0085 | 0.0032 | 2,431,576 | | | | |
| 4L | 0.0090 | 0.0032 | 2,258,112 | 4T | -0.0027 | -0.0010 | 0.3026 |
| Average | | | 2,341,277 | | | | 0.2737 |

Stress-Strain Curve 140_3_(09-04), Long.



Stress-Strain Curve 140_3_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MAT4-TX-4-140-FY09
 Test Date: 4/14/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 18,673 lbs
 Tensile Strength, ST_x : 42,796 psi
 Tensile Modulus, E_x : 2,116,903 psi
 Ultimate Strain, ϵ_x : 0.0202 in/in
 Poisson's Ratio, ν_{xy} : 0.2784

Measured Specimen Dimensions:

Width, W: 0.4886 in
 Thickness, H: 0.8930 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 3,735 lbs
 50% Max Load: 9,336 lbs

PICTURE OF SPECIMEN PRE-TEST



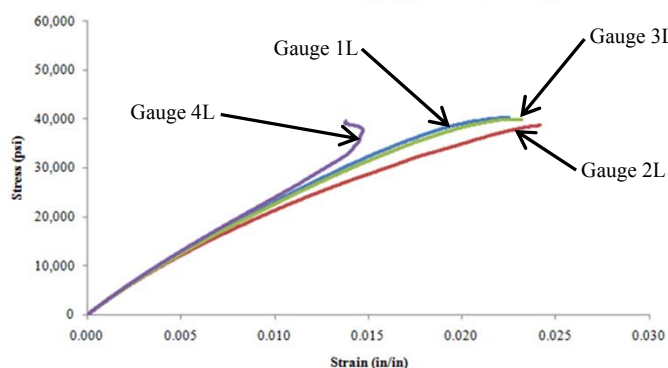
PICTURE OF SPECIMEN POST-TEST



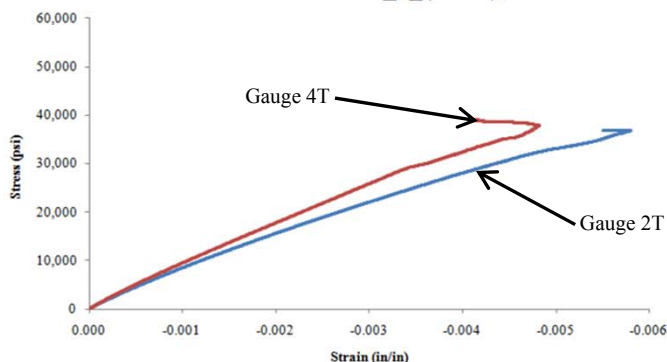
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0091 | 0.0032 | 2,175,684 | | | | |
| 2L | 0.0101 | 0.0033 | 1,908,644 | 2T | -0.0029 | -0.0010 | 0.2808 |
| 3L | 0.0094 | 0.0033 | 2,110,709 | | | | |
| 4L | 0.0088 | 0.0031 | 2,272,575 | 4T | -0.0024 | -0.0009 | 0.2760 |
| Average | | | 2,116,903 | | | | 0.2784 |

Stress-Strain Curve 140_4_(09-04), Long.



Stress-Strain Curve 140_4_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: MAT4-TX-5-140-FY09
 Test Date: 4/14/2011
 Specimen Received: 2/25/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 18,430 lbs
 Tensile Strength, ST_x : 44,188 psi
 Tensile Modulus, E_x : 2,351,656 psi
 Ultimate Strain, ϵ_x : 0.0188 in/in
 Poisson's Ratio, ν_{xy} : 0.2654

Measured Specimen Dimensions:

Width, W: 0.4670 in
 Thickness, H: 0.8931 in
 Laboratory Temperature: 68°F
 Failure Mode: Tensile Delamination
 20% Max Load: 3,686 lbs
 50% Max Load: 9,215 lbs

PICTURE OF SPECIMEN PRE-TEST



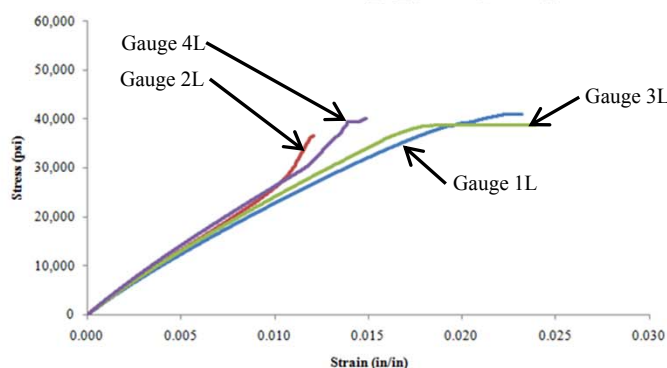
PICTURE OF SPECIMEN POST-TEST



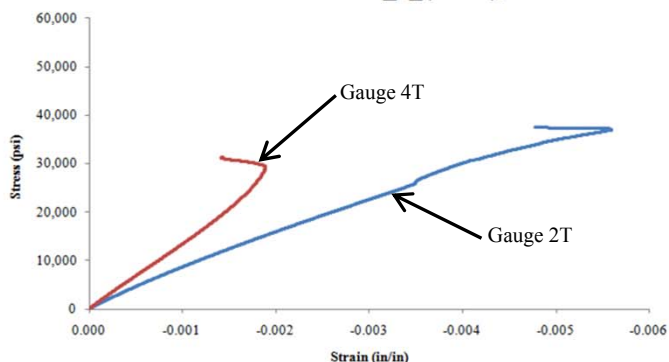
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0096 | 0.0034 | 2,136,615 | | | | |
| 2L | 0.0086 | 0.0032 | 2,455,041 | 2T | -0.0029 | -0.0010 | 0.3526 |
| 3L | 0.0091 | 0.0032 | 2,283,714 | | | | |
| 4L | 0.0082 | 0.0030 | 2,531,255 | 4T | -0.0016 | -0.0007 | 0.1782 |
| Average | | | 2,351,656 | | | | 0.2654 |

Stress-Strain Curve 140_5_(09-04), Long.



Stress-Strain Curve 140_5_(09-04), Lat.



Engineering Test notes:

- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Tensile Modulus and Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CX-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_x, E_x, ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x: 41,295 lbs

Compressive Strength, SC_x: 43,680 psi

Compressive Modulus, E_x: 2,957,847 psi

Ultimate Strain, ε_x: 0.015 in/in

Poisson's Ratio, ν_{xy}: 0.263

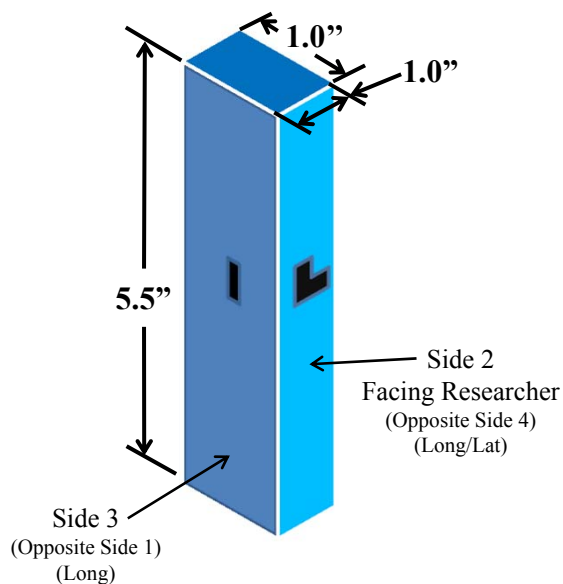
| Sample | Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|----------------|----------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| 1 | MAT4- CX-01-N40-FY09 | 43,925 | 48,365 | 2,975,091 | 0.016 | 0.299 | Delam |
| 2 | MAT4- CX-02-N40-FY09 | 38,584 | 40,717 | 2,936,775 | 0.014 | 0.283 | Delam |
| 3 | MAT4- CX-03-N40-FY09 | 41,507 | 42,571 | 2,820,448 | 0.015 | 0.244 | Delam |
| 4 | MAT4- CX-04-N40-FY09 | 41,537 | 43,742 | 2,862,685 | 0.015 | 0.240 | Delam |
| 5 | MAT4- CX-05-N40-FY09 | 40,921 | 43,003 | 3,194,234 | 0.014 | 0.248 | Delam |
| Average | | 41,295 | 43,680 | 2,957,847 | 0.015 | 0.263 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See G-20 to G-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT4-CX-01-N40-FY09
 Test Date: 4/4/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 43,925 lbs
 Compressive Strength, SC_x : 48,365 psi
 Compressive Modulus, E_x : 2,975,091 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson's Ratio, ν_{xy} : 0.299

Measured Specimen Dimensions:

Width, W: 0.95 in
 Thickness, H: 0.954 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 8,785 lbs
 50% Max Load: 21,962 lbs

PICTURE OF SPECIMEN PRE-TEST



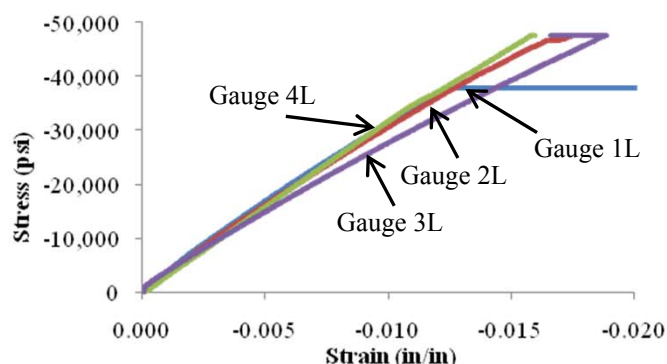
PICTURE OF SPECIMEN POST-TEST



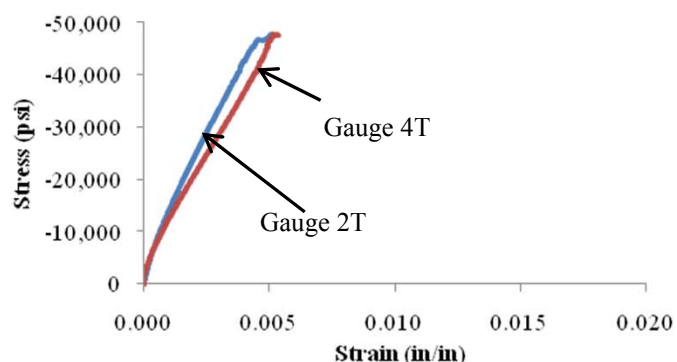
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0074 | -0.0027 | 3,072,089 | | | | |
| 2L | -0.0077 | -0.0029 | 2,984,840 | 2T | 0.0020 | 0.0006 | 0.283 |
| 3L | -0.0076 | -0.0031 | 3,214,259 | | | | |
| 4L | -0.0086 | -0.0031 | 2,629,175 | 4T | 0.0024 | 0.0007 | 0.316 |
| Average | | | 2,975,091 | | | | 0.299 |

Stress-Strain Curve N40_01_(09-04), Long



Stress-Strain Curve N40_01_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-02-N40-FY09**
 Test Date: 4/4/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 38,584 lbs
 Compressive Strength, SC_x : 40,717 psi
 Compressive Modulus, E_x : 2,936,775 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.283

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 7,717 lbs
 50% Max Load: 19,292 lbs

PICTURE OF SPECIMEN PRE-TEST



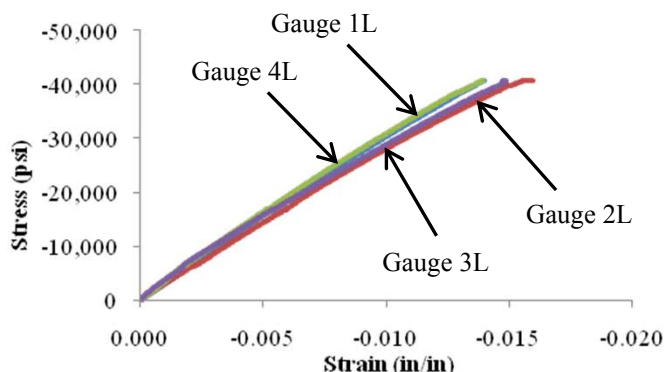
PICTURE OF SPECIMEN POST-TEST



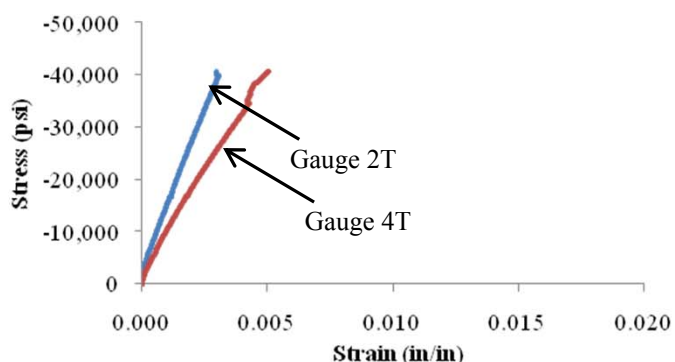
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0065 | -0.0026 | 3,076,154 | | | | |
| 2L | -0.0071 | -0.0028 | 2,874,935 | 2T | 0.0014 | 0.000 | 0.228 |
| 3L | -0.0063 | -0.0024 | 3,069,134 | | | | |
| 4L | -0.0068 | -0.0023 | 2,726,875 | 4T | 0.0023 | 0.0007 | 0.380 |
| Average | | | 2,936,775 | | | | 0.283 |

Stress-Strain Curve N40_02_(09-04), Long



Stress-Strain Curve N40_02_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT4-CX-03-N40-FY09
 Test Date: 4/6/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 41,507 lbs
 Compressive Strength, SC_x : 42,571 psi
 Compressive Modulus, E_x : 2,820,448 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.244

Measured Specimen Dimensions:

Width, W: 1.00 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 8,301 lbs
 50% Max Load: 20,754 lbs

PICTURE OF SPECIMEN PRE-TEST



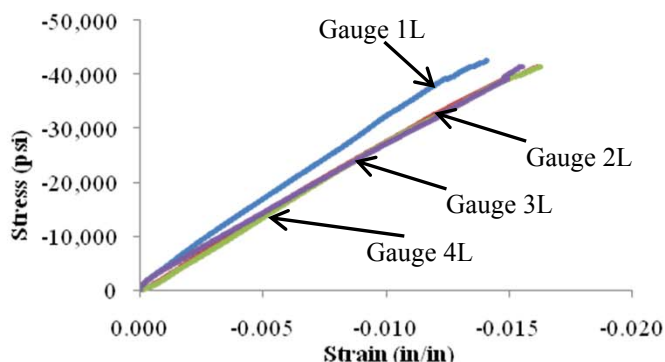
PICTURE OF SPECIMEN POST-TEST



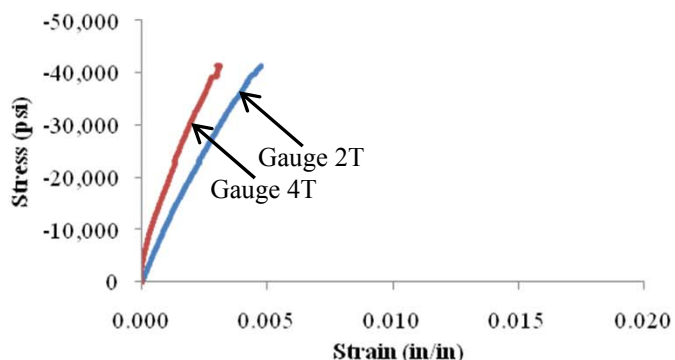
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0065 | -0.0023 | 3,043,595 | | | | |
| 2L | -0.0076 | -0.0030 | 2,792,178 | 2T | 0.0021 | 0.0008 | 0.294 |
| 3L | -0.0077 | -0.0033 | 2,864,997 | | | | |
| 4L | -0.0077 | -0.0027 | 2,581,022 | 4T | 0.0012 | 0.0003 | 0.193 |
| Average | | | 2,820,448 | | | | 0.244 |

Stress-Strain Curve N40_03_(09-04), Long



Stress-Strain Curve N40_03_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-04-N40-FY09**
 Test Date: 4/6/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 41,537 lbs
 Compressive Strength, SC_x : 43,742 psi
 Compressive Modulus, E_x : 2,862,685 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.240

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 8,307 lbs
 50% Max Load: 20,769 lbs

PICTURE OF SPECIMEN PRE-TEST



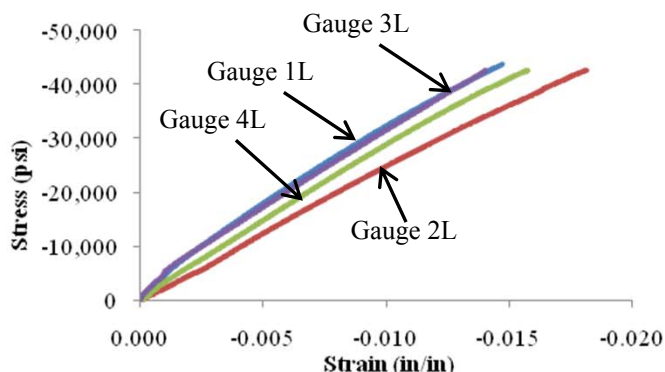
PICTURE OF SPECIMEN POST-TEST



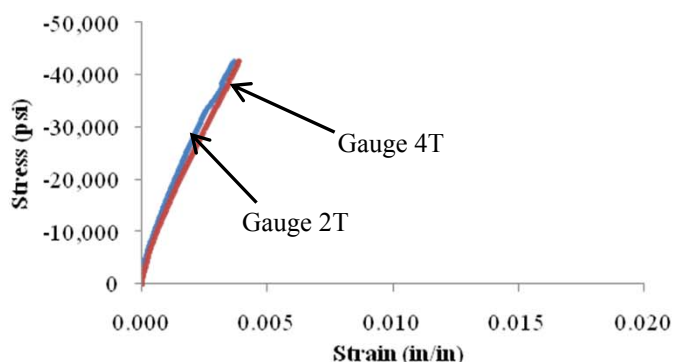
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0063 | -0.0021 | 3,107,107 | | | | |
| 2L | -0.0088 | -0.0037 | 2,565,349 | 2T | 0.0015 | 0.0004 | 0.211 |
| 3L | -0.0075 | -0.0029 | 2,871,233 | | | | |
| 4L | -0.0066 | -0.0021 | 2,907,051 | 4T | 0.0017 | 0.0005 | 0.268 |
| Average | | | 2,862,685 | | | | 0.240 |

Stress-Strain Curve N40_04_(09-04), Long



Stress-Strain Curve N40_04_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-05-N40-FY09**
 Test Date: 4/7/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 40,921 lbs
 Compressive Strength, SC_x : 43,003 psi
 Compressive Modulus, E_x : 3,194,234 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.248

Measured Specimen Dimensions:

Width, W: 0.97 in
 Thickness, H: 0.98 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 8,184 lbs
 50% Max Load: 20,461 lbs

PICTURE OF SPECIMEN PRE-TEST



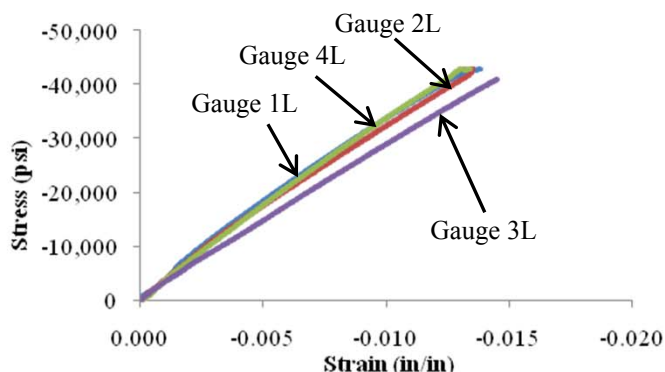
PICTURE OF SPECIMEN POST-TEST



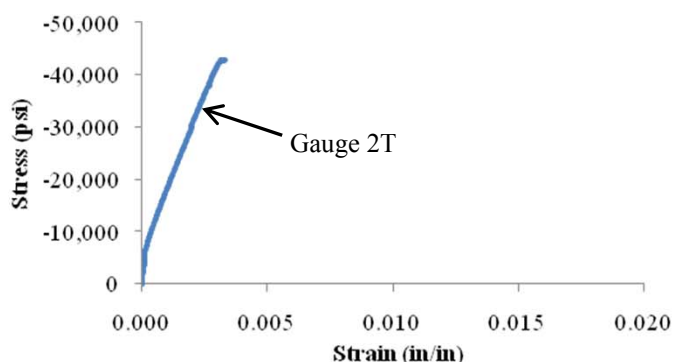
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0060 | -0.0021 | 3,334,236 | | | | |
| 2L | -0.0063 | -0.0023 | 3,200,506 | 2T | 0.0013 | 0.0008 | 0.248 |
| 3L | -0.0062 | -0.0024 | 3,412,745 | | | | |
| 4L | -0.0073 | -0.0028 | 2,829,451 | 4T | Lost Gauge | Lost Gauge | - |
| Average | | | 3,194,234 | | | | 0.248 |

Stress-Strain Curve N40_05_(09-04), Long



Stress-Strain Curve N40_05_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CX-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: SC_x, E_x, ν_{xy}

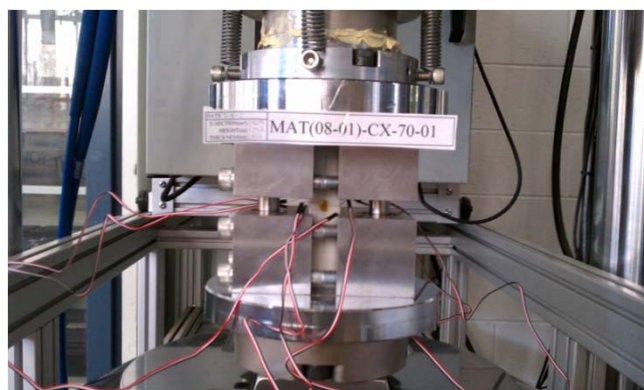
Average Material Properties (5 Specimens):

Ultimate Load, P_x: 33,321 lbs
 Compressive Strength, SC_x: 36,065 psi
 Compressive Modulus, E_x: 3,010,802 psi
 Ultimate Strain, ε_x: 0.012 in/in
 Poisson's Ratio, ν_{xy}: 0.257

| Sample | Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|----------------|--------------------|--------------------------------|---|---|---|----------------------------------|--------------|
| 1 | MAT4-CX-01-70-FY09 | 32,360 | 34,171 | 2,843,475 | 0.012 | 0.273 | Delam |
| 2 | MAT4-CX-02-70-FY09 | 29,871 | 31,643 | 3,413,058 | 0.009 | 0.247 | Delam |
| 3 | MAT4-CX-03-70-FY09 | 33,721 | 36,259 | 3,141,881 | 0.012 | 0.264 | Delam |
| 4 | MAT4-CX-04-70-FY09 | 35,072 | 36,917 | 2,832,319 | 0.013 | 0.225 | Delam |
| 5 | MAT4-CX-05-70-FY09 | 35,534 | 36,333 | 2,823,279 | 0.013 | 0.276 | Delam |
| Average | | 33,312 | 35,065 | 3,010,802 | 0.012 | 0.257 | |

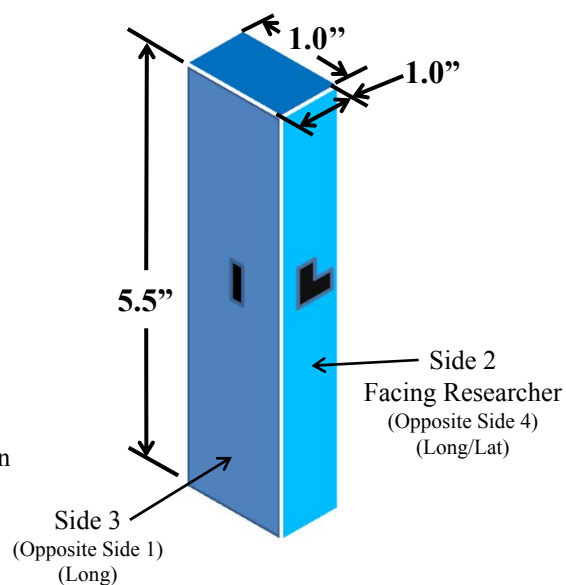
Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See G-26 to G-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

G-25

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-01-70-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 32,360 lbs
 Compressive Strength, SC_x : 34,171 psi
 Compressive Modulus, E_x : 2,843,515 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, v_{xy} : 0.273

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 0.95 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 6,472 lbs
 50% Max Load: 16,180 lbs

PICTURE OF SPECIMEN PRE-TEST



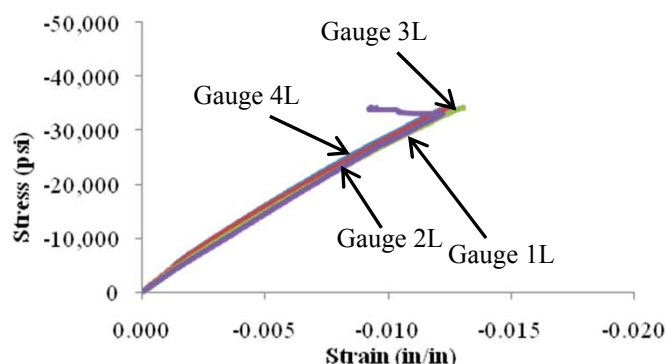
PICTURE OF SPECIMEN POST-TEST



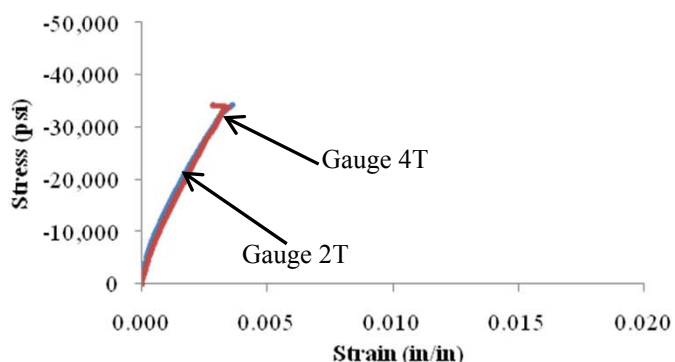
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.0054 | -0.0018 | 2,898,475 | | | | |
| 2L | -0.0055 | -0.0019 | 2,861,729 | 2T | 0.0013 | 0.0003 | 0.271 |
| 3L | -0.0058 | -0.0021 | 2,807,627 | | | | |
| 4L | -0.0059 | -0.0023 | 2,806,231 | 4T | 0.0014 | 0.0004 | 0.275 |
| Average | | | 2,843,515 | | | | 0.273 |

Stress-Strain Curve 70F_01_(09-04), Long



Stress-Strain Curve 70F_01_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-02-70-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 29,871 lbs
 Compressive Strength, SC_x : 31,643 psi
 Compressive Modulus, E_x : 3,413,058 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.247

Measured Specimen Dimensions:

Width, W: 0.97 in
 Thickness, H: 0.98 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 5,974 lbs
 50% Max Load: 14,935 lbs

PICTURE OF SPECIMEN PRE-TEST



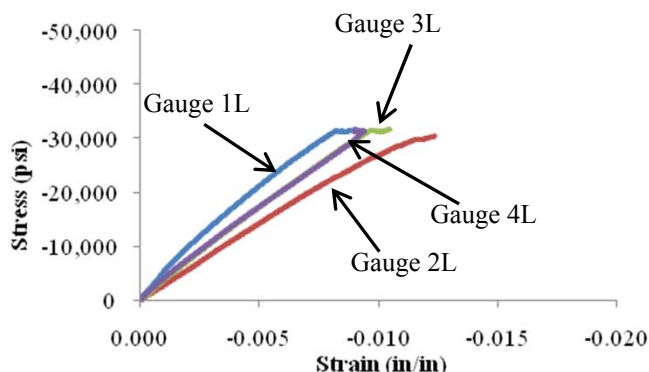
PICTURE OF SPECIMEN POST-TEST



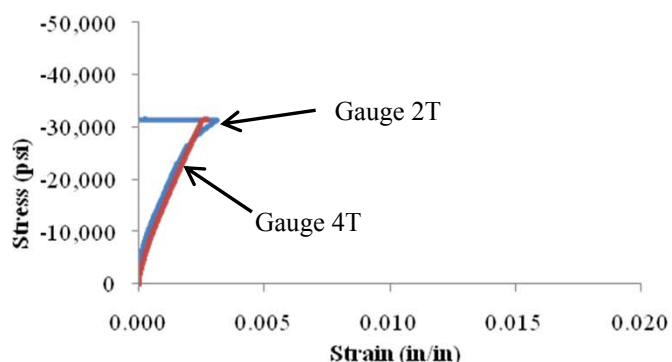
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0035 | -0.0012 | 4,076,302 | | | | |
| 2L | -0.0056 | -0.0023 | 2,879,239 | 2T | 0.0009 | 0.0001 | 0.225 |
| 3L | -0.0045 | -0.0017 | 3,393,389 | | | | |
| 4L | -0.0045 | -0.0016 | 3,303,299 | 4T | 0.0011 | 0.0003 | 0.269 |
| Average | | | 3,413,058 | | | | 0.247 |

Stress-Strain Curve 70F_02_(09-04), Long



Stress-Strain Curve_70F_02_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-03-70-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 33,721 lbs
 Compressive Strength, SC_x : 36,259 psi
 Compressive Modulus, E_x : 3,141,881 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.264

Measured Specimen Dimensions:

Width, W: 0.97 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 6,744 lbs
 50% Max Load: 16,861 lbs

PICTURE OF SPECIMEN PRE-TEST



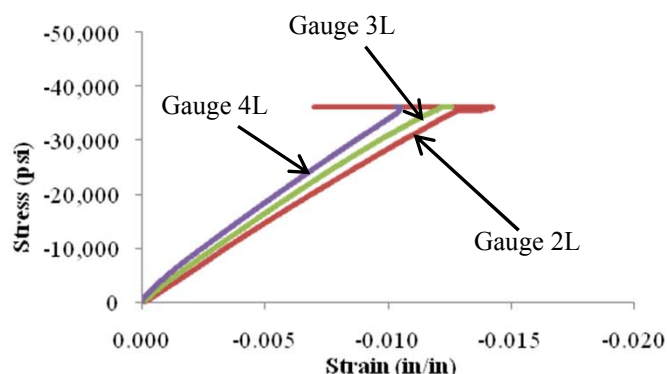
PICTURE OF SPECIMEN POST-TEST



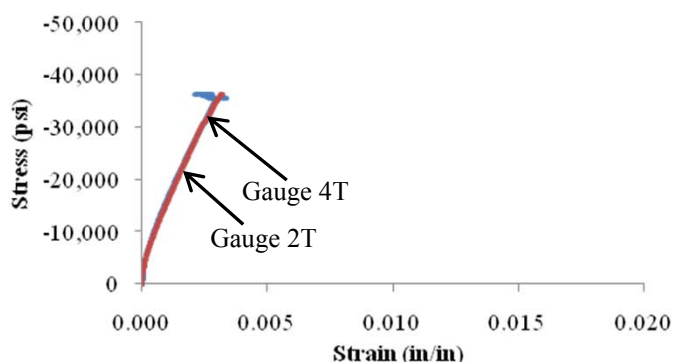
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.0062 | -0.0025 | 2,904,139 | 2T | 0.0012 | 0.0003 | 0.244 |
| 3L | -0.0055 | -0.0021 | 3,105,363 | | | | |
| 4L | -0.0049 | -0.0016 | 2,860,308 | 4T | 0.0012 | 0.0003 | 0.285 |
| Average | | | 3,007,855 | | | | 0.264 |

Stress-Strain Curve 70F_03_(09-04), Long



Stress-Strain Curve 70F_03_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-04-70-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 35,072 lbs
 Compressive Strength, SC_x : 36,917 psi
 Compressive Modulus, E_x : 2,832,319 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, v_{xy} : 0.225

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 0.98 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 7,014 lbs
 50% Max Load: 17,536 lbs

PICTURE OF SPECIMEN PRE-TEST



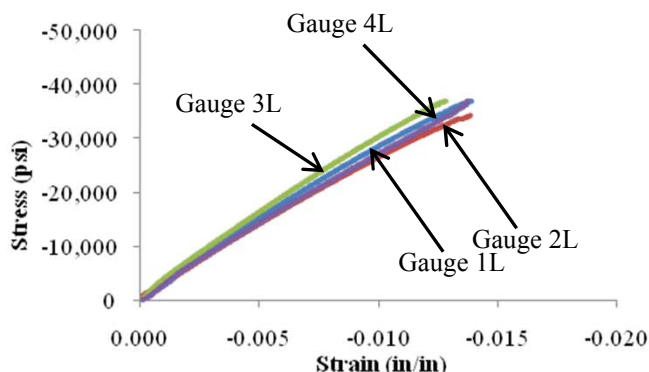
PICTURE OF SPECIMEN POST-TEST



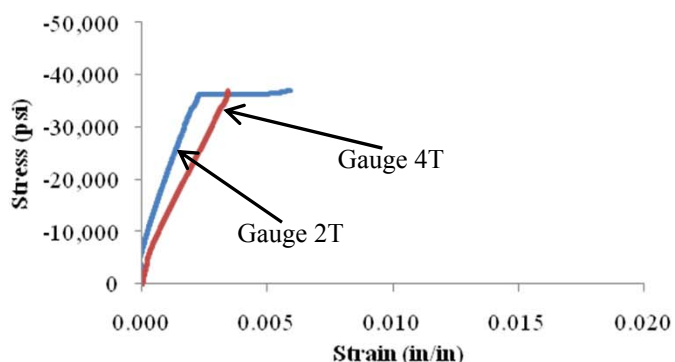
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.0061 | -0.0023 | 2,915,797 | | | | |
| 2L | -0.0067 | -0.0025 | 2,676,440 | 2T | 0.0008 | 0.0001 | 0.179 |
| 3L | -0.0057 | -0.0020 | 3,033,299 | | | | |
| 4L | -0.0065 | -0.0025 | 2,703,739 | 4T | 0.0015 | 0.0004 | 0.271 |
| Average | | | 2,832,319 | | | | 0.225 |

Stress-Strain Curve 70F_04_(09-04), Long



Stress-Strain Curve 70F_04_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-05-70-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 35,534 lbs
 Compressive Strength, SC_x : 36,333 psi
 Compressive Modulus, E_x : 2,823,279 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.276

Measured Specimen Dimensions:

Width, W: 1.01 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 7,107 lbs
 50% Max Load: 17,767 lbs

PICTURE OF SPECIMEN PRE-TEST



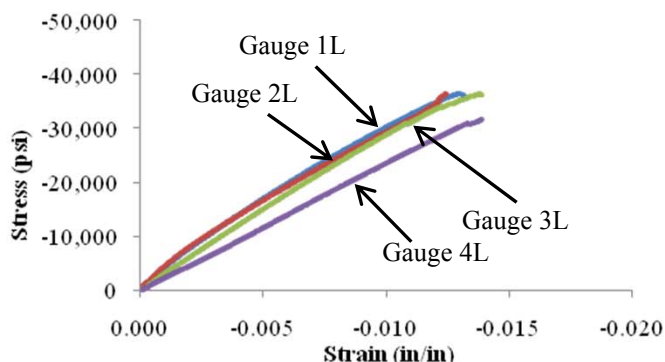
PICTURE OF SPECIMEN POST-TEST



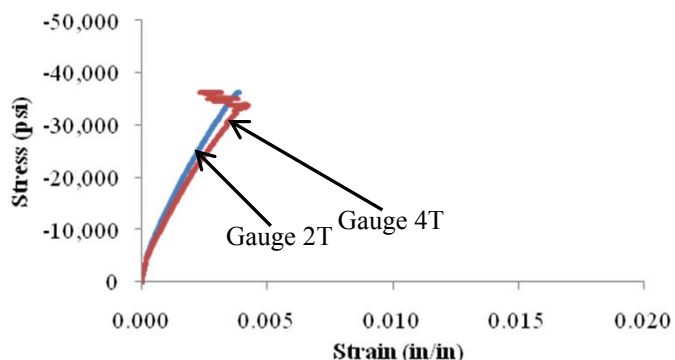
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0054 | -0.0019 | 3,048,984 | | | | |
| 2L | -0.0056 | -0.0018 | 2,877,890 | 2T | 0.0014 | 0.0004 | 0.280 |
| 3L | -0.0060 | -0.0024 | 2,942,815 | | | | |
| 4L | -0.0077 | -0.0032 | 2,423,425 | 4T | 0.0017 | 0.0005 | 0.273 |
| Average | | | 2,823,279 | | | | 0.276 |

Stress-Strain Curve 70F_05_(09-04), Long



Stress-Strain Curve 70F_05_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CX-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: SC_x, E_x, ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x: 28,161 lbs

Compressive Strength, SC_x: 30,672 psi

Compressive Modulus, E_x: 2,789,322 psi

Ultimate Strain, ε_x: 0.011 in/in

Poisson's Ratio, ν_{xy}: 0.250

| Sample | Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, ν _{xy} | Failure Mode |
|----------------|---------------------|--------------------------------|---|---|---|----------------------------------|--------------|
| 1 | MAT4-CX-01-140-FY09 | 31,378 | 34,069 | 2,711,183 | 0.013 | 0.242 | Delam |
| 2 | MAT4-CX-02-140-FY09 | 28,996 | 31,179 | 2,685,010 | 0.012 | 0.288 | Delam |
| 3 | MAT4-CX-03-140-FY09 | 28,872 | 31,520 | 2,844,825 | 0.011 | 0.194 | Delam |
| 4 | MAT4-CX-04-140-FY09 | 24,103 | 26,285 | 2,859,737 | 0.009 | 0.246 | Delam |
| 5 | MAT4-CX-05-140-FY09 | 27,456 | 30,305 | 2,845,856 | 0.011 | 0.282 | Delam |
| Average | | 28,161 | 30,672 | 2,789,322 | 0.011 | 0.250 | |

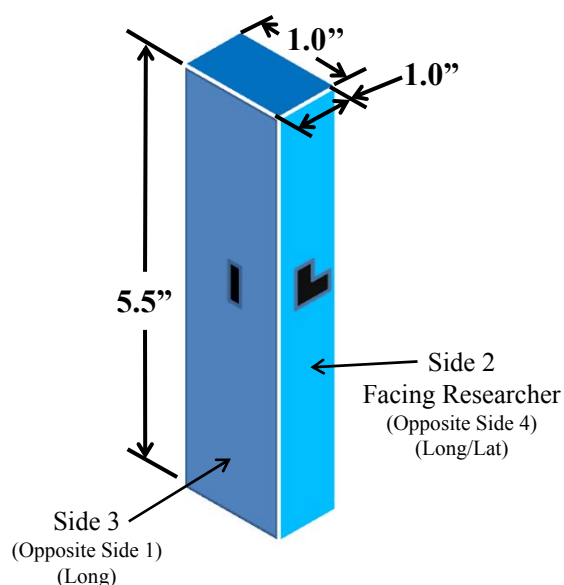
Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See G-32 to G-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

G-31

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT4-CX-01-140-FY09
 Test Date: 4/22/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 31,378 lbs
 Compressive Strength, SC_x : 34,069 psi
 Compressive Modulus, E_x : 2,711,183 psi
 Ultimate Strain, ϵ_x : 0.013 in/in
 Poisson's Ratio, ν_{xy} : 0.242

Measured Specimen Dimensions:

Width, W: 0.98 in
 Thickness, H: 0.94 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 6,276 lbs
 50% Max Load: 15,689 lbs

PICTURE OF SPECIMEN PRE-TEST



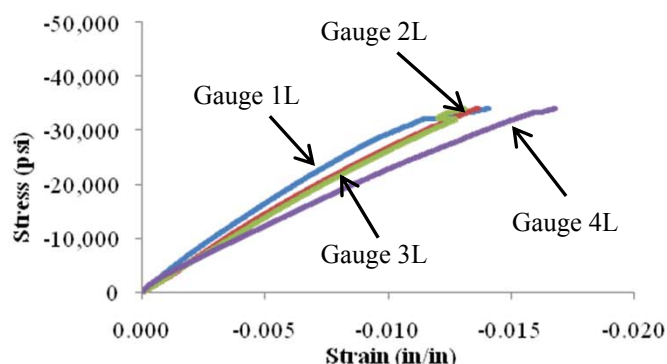
PICTURE OF SPECIMEN POST-TEST



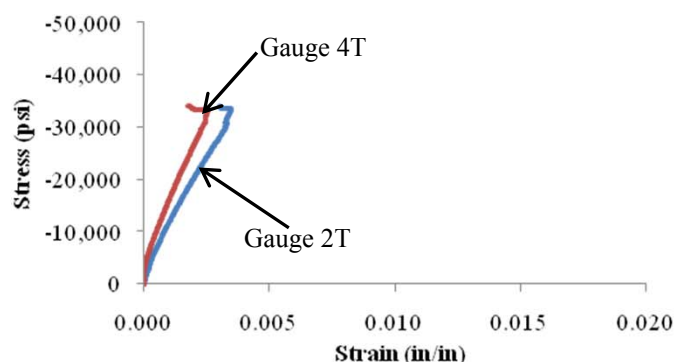
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0052 | -0.0019 | 3,074,634 | | | | |
| 2L | -0.0059 | -0.0023 | 2,844,581 | 2T | 0.0016 | 0.0005 | 0.305 |
| 3L | -0.0062 | -0.0025 | 2,735,333 | | | | |
| 4L | -0.0072 | -0.0025 | 2,190,183 | 4T | 0.0011 | 0.0003 | 0.179 |
| Average | | | 2,711,183 | | | | 0.242 |

Stress-Strain Curve 140F_01_(09-04), Long



Stress-Strain Curve 140F_01_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-02-140-FY09**
 Test Date: 4/22/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 28,996 lbs
 Compressive Strength, SC_x : 31,179 psi
 Compressive Modulus, E_x : 2,685,010 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.288

Measured Specimen Dimensions:

Width, W: 0.96 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 5,799 lbs
 50% Max Load: 14,498 lbs

PICTURE OF SPECIMEN PRE-TEST



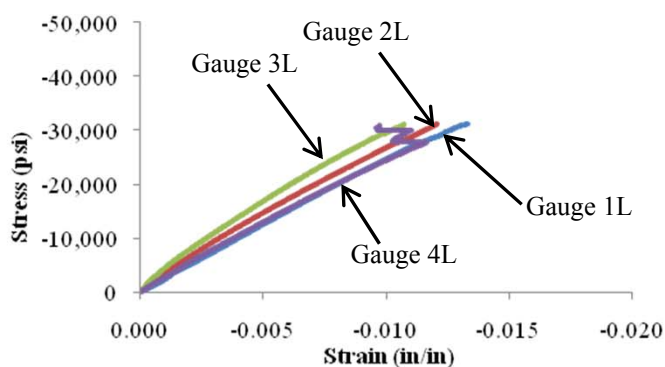
PICTURE OF SPECIMEN POST-TEST



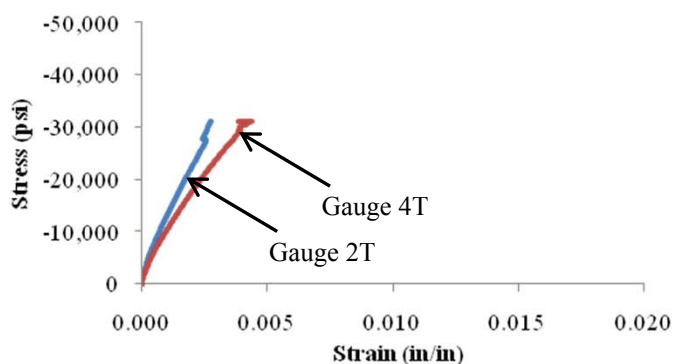
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0062 | -0.0025 | 2,519,167 | | | | |
| 2L | -0.0053 | -0.0019 | 2,714,379 | 2T | 0.0013 | 0.0004 | 0.260 |
| 3L | -0.0046 | -0.0015 | 3,048,654 | | | | |
| 4L | -0.0061 | -0.0022 | 2,457,841 | 4T | 0.0017 | 0.0005 | 0.316 |
| Average | | | 2,685,010 | | | | 0.288 |

Stress-Strain Curve 140F_02_(09-04), Long



Stress-Strain Curve 140F_02_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT4-CX-03-140-FY09
 Test Date: 4/22/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 28,872 lbs
 Compressive Strength, SC_x : 31,520 psi
 Compressive Modulus, E_x : 2,844,825 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.194

Measured Specimen Dimensions:

Width, W: 0.95 in
 Thickness, H: 0.96 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 5,774 lbs
 50% Max Load: 14,436 lbs

PICTURE OF SPECIMEN PRE-TEST



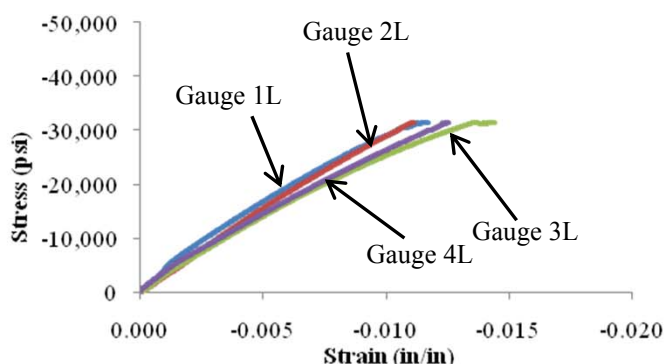
PICTURE OF SPECIMEN POST-TEST



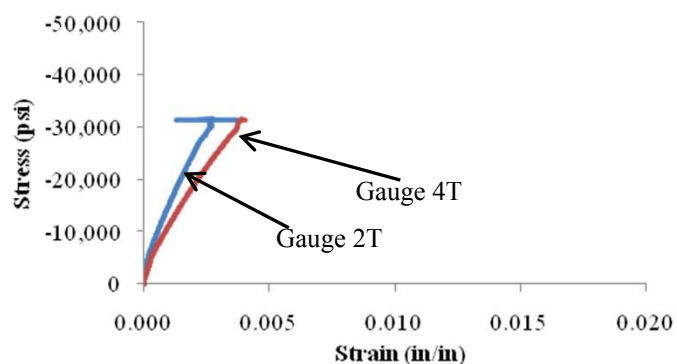
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0046 | -0.0015 | 2,993,423 | | | | |
| 2L | -0.0051 | -0.0021 | 3,162,553 | 2T | 0.0011 | 0.0003 | 0.269 |
| 3L | -0.0027 | -0.0021 | 2,643,760 | | | | |
| 4L | -0.0055 | -0.0018 | 2,579,565 | 4T | 0.0016 | 0.0004 | 0.313 |
| Average | | | 2,844,825 | | | | 0.194 |

Stress-Strain Curve 140F_03_(09-04), Long



Stress-Strain Curve 140F_03_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: MAT4-CX-04-140-FY09
 Test Date: 4/22/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 24,103 lbs
 Compressive Strength, SC_x : 26,285 psi
 Compressive Modulus, E_x : 2,859,737 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.246

Measured Specimen Dimensions:

Width, W: 0.96 in
 Thickness, H: 0.96 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 4,821 lbs
 50% Max Load: 12,052 lbs

PICTURE OF SPECIMEN PRE-TEST



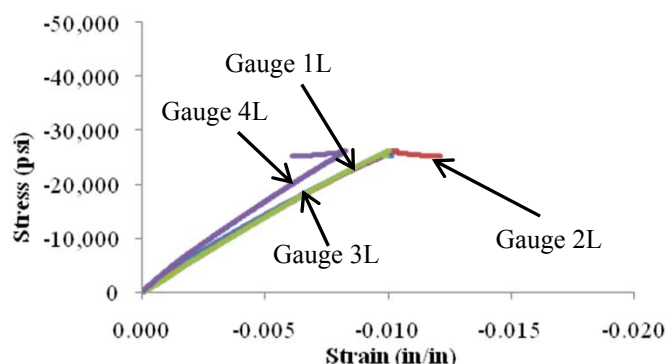
PICTURE OF SPECIMEN POST-TEST



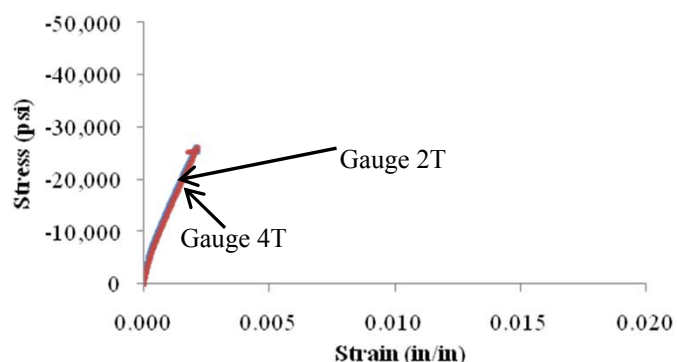
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.0045 | -0.0016 | 2,708,046 | | | | |
| 2L | -0.0045 | -0.0018 | 2,770,261 | 2T | 0.0008 | 0.0002 | 0.225 |
| 3L | -0.0047 | -0.0018 | 2,747,467 | | | | |
| 4L | -0.0038 | -0.0013 | 3,213,174 | 4T | 0.0009 | 0.0003 | 0.267 |
| Average | | | 2,859,737 | | | | 0.246 |

Stress-Strain Curve 140F_04_(09-04), Long



Stress-Strain Curve 140F_04_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-05-140-FY09**
 Test Date: 4/25/2011
 Specimen Received: 3/17/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 27,456 lbs
 Compressive Strength, SC_x : 30,305 psi
 Compressive Modulus, E_x : 2,845,856 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, v_{xy} : 0.282

Measured Specimen Dimensions:

Width, W: 0.94 in
 Thickness, H: 0.97 in
 Laboratory Temperature: 68°F
 Failure Mode: Delamination
 20% Max Load: 5,491 lbs
 50% Max Load: 13,728 lbs

PICTURE OF SPECIMEN PRE-TEST



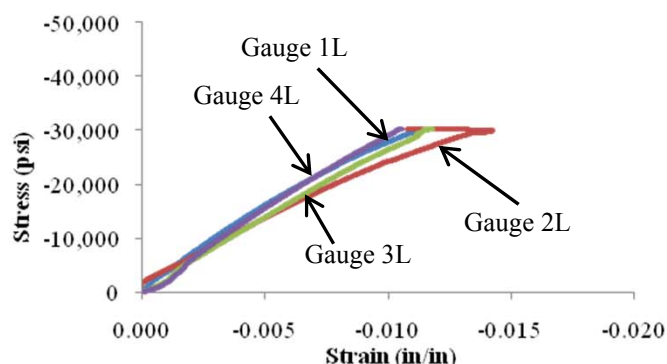
PICTURE OF SPECIMEN POST-TEST



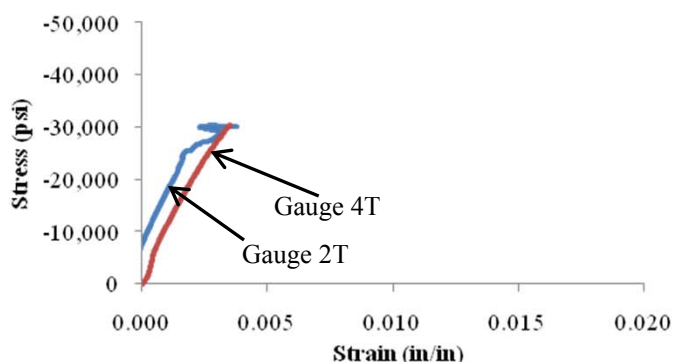
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.0046 | -0.0017 | 3,066,686 | | | | |
| 2L | -0.0056 | -0.0019 | 2,424,822 | 2T | 0.0007 | 0.0001 | 0.230 |
| 3L | -0.0055 | -0.0021 | 2,698,022 | | | | |
| 4L | -0.0049 | -0.0020 | 3,193,894 | 4T | 0.0014 | 0.0005 | 0.334 |
| Average | | | 2,845,856 | | | | 0.282 |

Stress-Strain Curve 140F_05_(09-04), Long



Stress-Strain Curve 140F_05_(09-04), Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXY-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 19,073 lbs

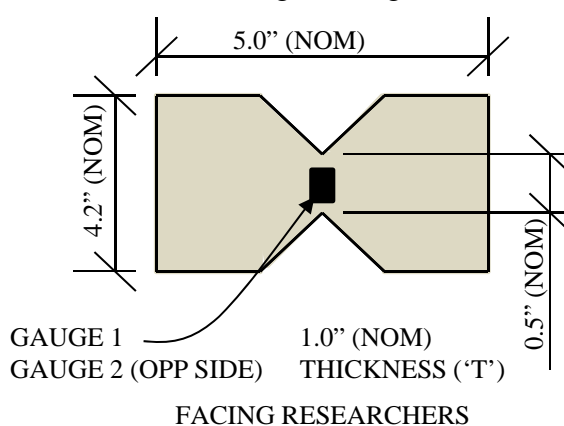
Shear Strength, S_{xy} : 37,942 psi

Shear Modulus, G_{xy} : 1,875,351 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT4-SXY-01-N40-FY09 | 21,100 | 38,434 | 1,588,497 | Shear |
| 2 | MAT4-SXY-02-N40-FY09 | 18,012 | 36,535 | 1,915,968 | Shear |
| 3 | MAT4-SXY-03-N40-FY09 | 18,894 | 38,481 | 1,853,955 | Shear |
| 4 | MAT4-SXY-04-N40-FY09 | 18,622 | 38,715 | 1,968,223 | Shear |
| 5 | MAT4-SXY-05-N40-FY09 | 18,735 | 37,545 | 1,875,113 | Shear |
| Average | | 19,073 | 37,942 | 1,875,351 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets G-38 to G-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-01-N40-FY09
 Test Date: 5/9/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 21,100 lbs
 Shear Stress, S_{xy} : 38,434 psi
 Shear Modulus, G_{xy} : 1,588,497 psi

Measured Specimen Dimensions:

Thickness, T: 0.97 in
 Notch Length, N: 0.57 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 4,220 lbs
 50% Max Load: 10,550 lbs

PICTURE OF SPECIMEN PRE-TEST



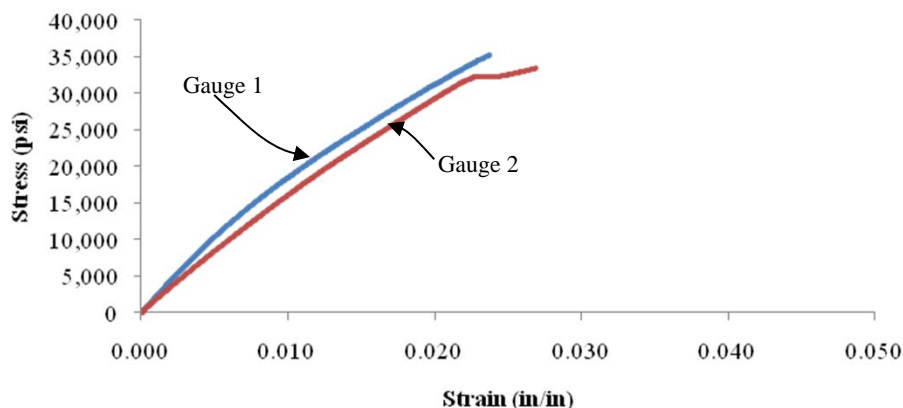
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0105 | 0.0036 | 1,668,691 |
| 2 | 0.0122 | 0.0045 | 1,508,303 |
| Average | | | 1,588,497 |

Stress-Strain Curve N40_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-02-N40-FY09
 Test Date: 5/17/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

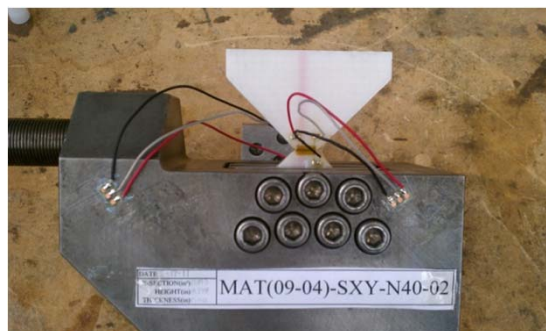
Average Material Properties:

Ultimate Load, P_{max} : 18,012 lbs
 Shear Stress, S_{xy} : 36,535 psi
 Shear Modulus, G_{xy} : 1,915,968 psi

Measured Specimen Dimensions:

Thickness, T : 0.90 in
 Notch Length, N : 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,602 lbs
 50% Max Load: 9,006 lbs

PICTURE OF SPECIMEN PRE-TEST



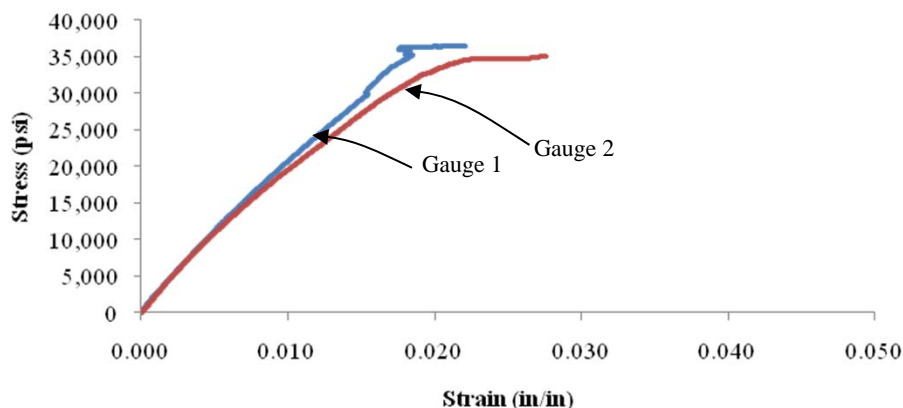
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0086 | 0.0031 | 1,999,516 |
| 2 | 0.0092 | 0.0032 | 1,832,419 |
| Average | | | 1,915,968 |

Stress-Strain Curve N40_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-03-N40-FY09
 Test Date: 5/17/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,894 lbs
 Shear Stress, S_{xy} : 38,481 psi
 Shear Modulus, G_{xy} : 1,853,955 psi

Measured Specimen Dimensions:

Thickness, T: 0.90 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,779 lbs
 50% Max Load: 9,447 lbs

PICTURE OF SPECIMEN PRE-TEST



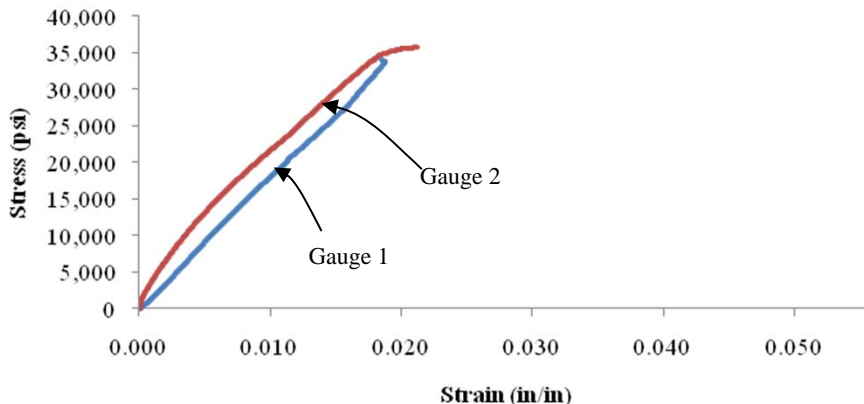
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0108 | 0.0043 | 1,779,663 |
| 2 | 0.0085 | 0.0025 | 1,928,248 |
| Average | | | 1,853,955 |

Stress-Strain Curve N40_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-04-N40-FY09
 Test Date: 5/18/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,622 lbs
 Shear Stress, S_{xy} : 38,715 psi
 Shear Modulus, G_{xy} : 1,968,223 psi

Measured Specimen Dimensions:

Thickness, T : 0.90 in
 Notch Length, N : 0.53 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,724 lbs
 50% Max Load: 9,311 lbs

PICTURE OF SPECIMEN PRE-TEST



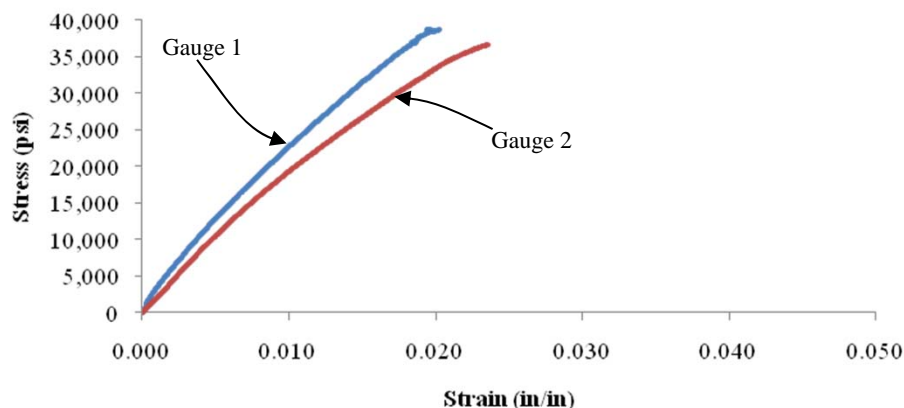
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0082 | 0.0027 | 2,121,781 |
| 2 | 0.0100 | 0.0036 | 1,814,665 |
| Average | | | 1,968,223 |

Stress-Strain Curve N40_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-05-N40-FY09
 Test Date: 5/18/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 18,375 lbs
 Shear Stress, S_{xy} : 37,545 psi
 Shear Modulus, G_{xy} : 1,875,113 psi

Measured Specimen Dimensions:

Thickness, T: 0.91 in
 Notch Length, N: 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,747 lbs
 50% Max Load: 9,367 lbs

PICTURE OF SPECIMEN PRE-TEST



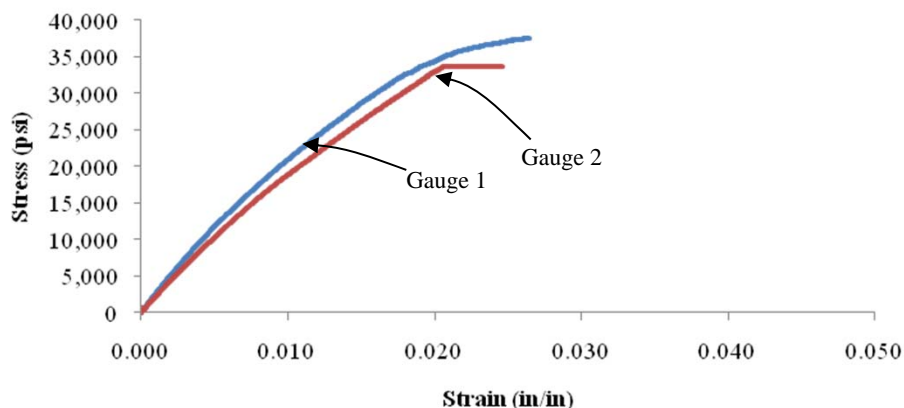
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0087 | 0.0030 | 1,984,726 |
| 2 | 0.0095 | 0.0035 | 1,765,500 |
| Average | | | 1,875,113 |

Stress-Strain Curve N40_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXY-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 16,088 lbs

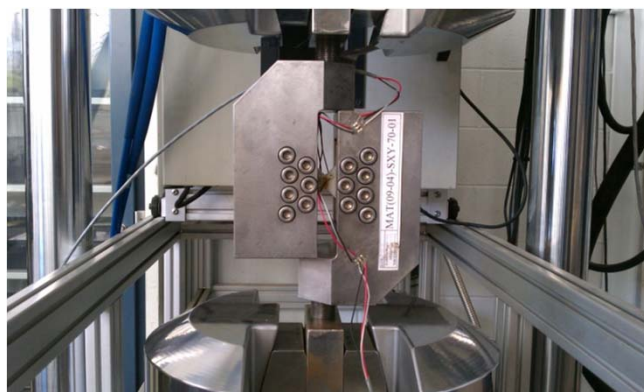
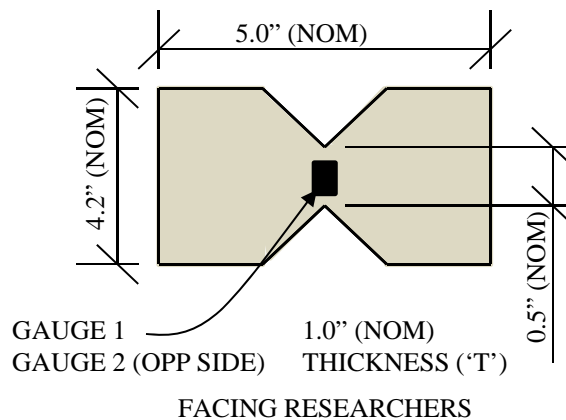
Shear Strength, S_{xy} : 31,530 psi

Shear Modulus, G_{xy} : 1,547,881 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT4-SXY-01-70-FY09 | 15,701 | 31,340 | 1,509,795 | Shear |
| 2 | MAT4-SXY-02-70-FY09 | 16,546 | 32,127 | 1,571,792 | Shear |
| 3 | MAT4-SXY-03-70-FY09 | 15,847 | 31,855 | 1,686,956 | Shear |
| 4 | MAT4-SXY-04-70-FY09 | 15,492 | 32,009 | 1,567,488 | Shear |
| 5 | MAT4-SXY-05-70-FY09 | 16,856 | 30,317 | 1,403,373 | Shear |
| Average | | 16,088 | 31,530 | 1,547,881 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets G-44 to G-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-01-70-FY09
 Test Date: 5/2/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 15,701 lbs
 Shear Stress, S_{xy} : 31,340 psi
 Shear Modulus, G_{xy} : 1,509,795 psi

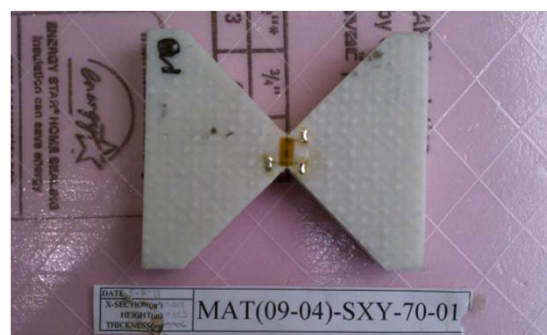
Measured Specimen Dimensions:

Thickness, T : 0.91 in
 Notch Length, N : 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,140 lbs
 50% Max Load: 7,851 lbs

PICTURE OF SPECIMEN PRE-TEST



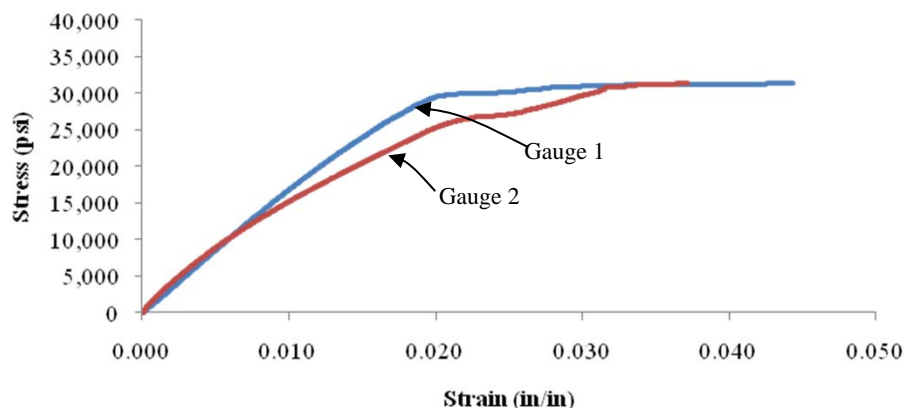
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0092 | 0.0037 | 1,693,161 |
| 2 | 0.0104 | 0.0033 | 1,326,429 |
| Average | | | 1,509,795 |

Stress-Strain Curve 70F_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-02-70-FY09
 Test Date: 5/3/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 16,546 lbs
 Shear Stress, S_{xy} : 32,127 psi
 Shear Modulus, G_{xy} : 1,571,792 psi

Measured Specimen Dimensions:

Thickness, T: 0.90 in
 Notch Length, N: 0.57 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,309 lbs
 50% Max Load: 8,273 lbs

PICTURE OF SPECIMEN PRE-TEST



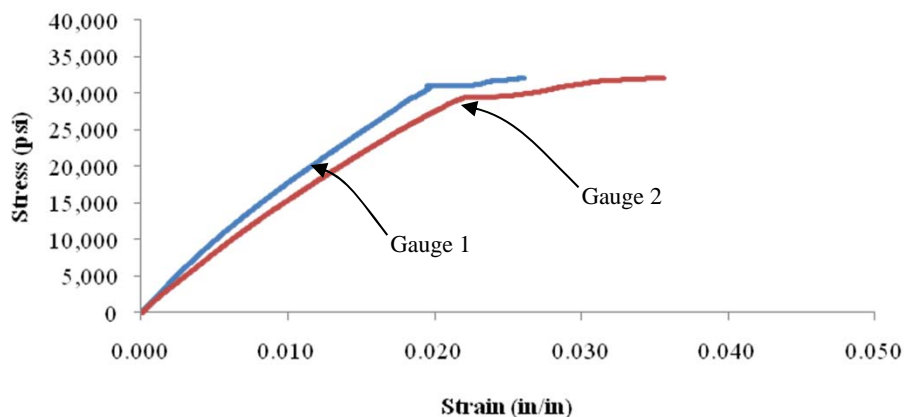
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0088 | 0.0031 | 1,684,405 |
| 2 | 0.0105 | 0.0039 | 1,459,179 |
| Average | | | 1,571,792 |

Stress-Strain Curve 70F_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-03-70-FY09
 Test Date: 5/3/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 15,847 lbs
 Shear Stress, S_{xy} : 31,855 psi
 Shear Modulus, G_{xy} : 1,686,956 psi

Measured Specimen Dimensions:

Thickness, T : 0.90 in
 Notch Length, N : 0.55 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,169 lbs
 50% Max Load: 7,924 lbs

PICTURE OF SPECIMEN PRE-TEST



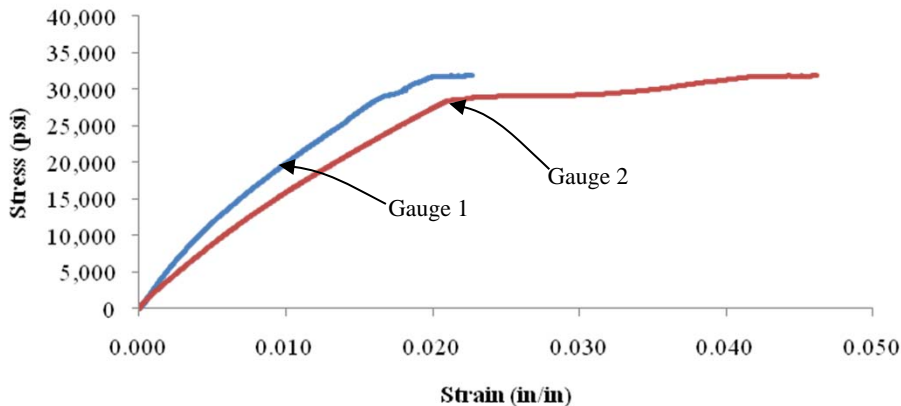
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0074 | 0.0024 | 1,913,677 |
| 2 | 0.0100 | 0.0035 | 1,460,235 |
| Average | | | 1,686,956 |

Stress-Strain Curve 70F_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-04-70-FY09
 Test Date: 5/3/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 15,492 lbs
 Shear Stress, S_{xy} : 32,009 psi
 Shear Modulus, G_{xy} : 1,567,488 psi

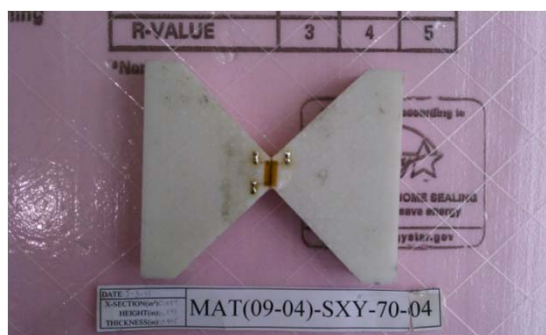
Measured Specimen Dimensions:

Thickness, T: 0.90 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,098 lbs
 50% Max Load: 7,746 lbs

PICTURE OF SPECIMEN PRE-TEST



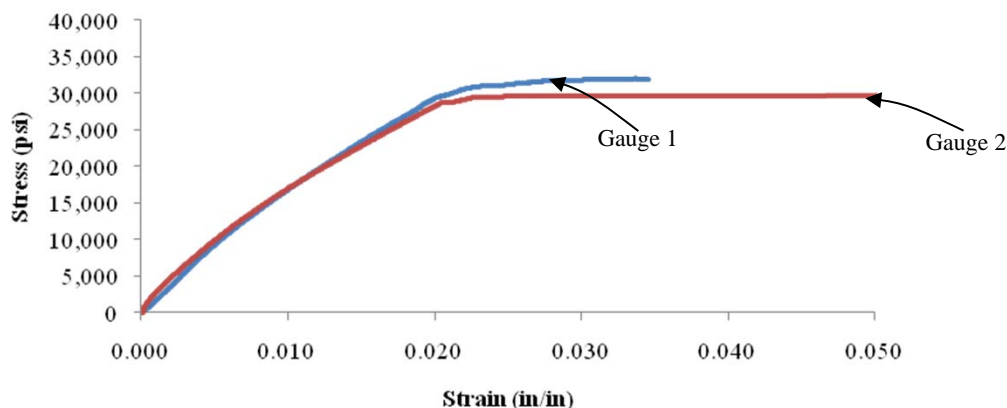
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0094 | 0.0034 | 1,610,489 |
| 2 | 0.0092 | 0.0029 | 1,524,487 |
| Average | | | 1,567,488 |

Stress-Strain Curve 70F_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-05-70-FY09
 Test Date: 5/4/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 16,856 lbs
 Shear Stress, S_{xy} : 30,317 psi
 Shear Modulus, G_{xy} : 1,403,373 psi

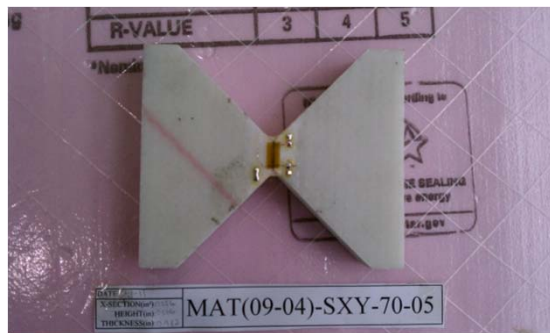
Measured Specimen Dimensions:

Thickness, T: 0.98 in
 Notch Length, N: 0.57 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,371 lbs
 50% Max Load: 8,428 lbs

PICTURE OF SPECIMEN PRE-TEST



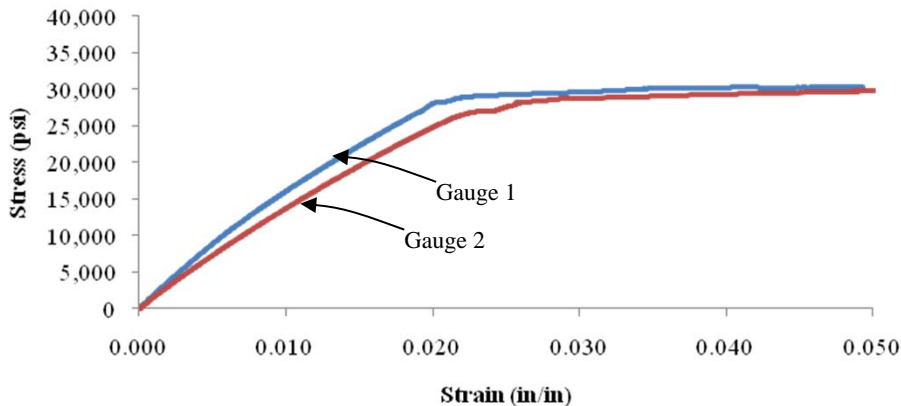
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0093 | 0.0033 | 1,523,939 |
| 2 | 0.0112 | 0.0041 | 1,282,807 |
| Average | | | 1,403,373 |

Stress-Strain Curve 70F_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXY-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 12,935 lbs

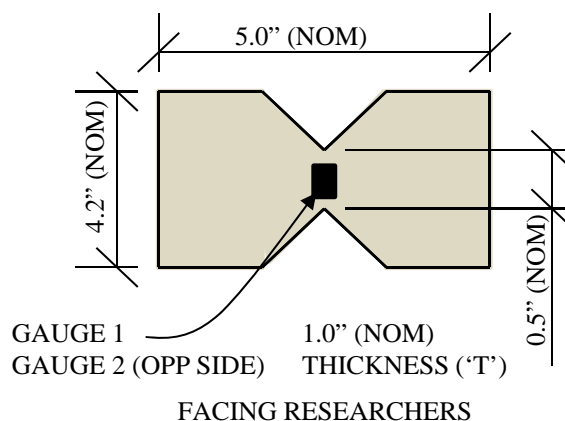
Shear Strength, S_{xy} : 25,399 psi

Shear Modulus, G_{xy} : 1,507,830 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT4-SXY-01-140-FY09 | 13,259 | 27,226 | 1,782,560 | Shear |
| 2 | MAT4-SXY-02-140-FY09 | 13,006 | 25,402 | 1,576,918 | Shear |
| 3 | MAT4-SXY-03-140-FY09 | 13,083 | 24,050 | 1,303,147 | Shear |
| 4 | MAT4-SXY-04-140-FY09 | 12,280 | 23,798 | 1,478,597 | Shear |
| 5 | MAT4-SXY-05-140-FY09 | 13,047 | 26,519 | 1,397,929 | Shear |
| Average | | 12,935 | 25,399 | 1,507,830 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets G-50 to G-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-01-140-FY09
 Test Date: 5/10/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 13,259 lbs
 Shear Stress, S_{xy} : 27,226 psi
 Shear Modulus, G_{xy} : 1,782,560 psi

Measured Specimen Dimensions:

Thickness, T: 0.90 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,652 lbs
 50% Max Load: 6,630 lbs

PICTURE OF SPECIMEN PRE-TEST



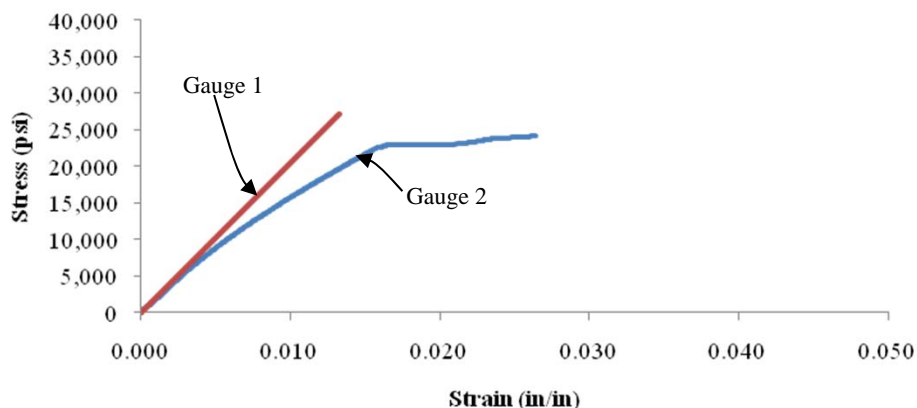
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0083 | 0.0029 | 1,511,307 |
| 2 | 0.0063 | 0.0027 | 2,053,814 |
| Average | | | 1,782,560 |

Stress-Strain Curve 140F_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-02-140-FY09
 Test Date: 5/10/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 13,006 lbs
 Shear Stress, S_{xy} : 25,402 psi
 Shear Modulus, G_{xy} : 1,576,918 psi

Measured Specimen Dimensions:

Thickness, T: 0.90 in
 Notch Length, N: 0.57 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,601 lbs
 50% Max Load: 6,503 lbs

PICTURE OF SPECIMEN PRE-TEST



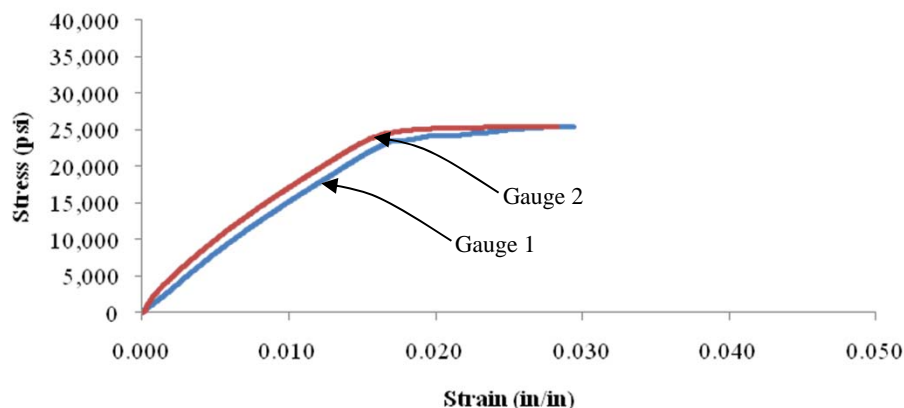
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0081 | 0.0031 | 1,512,641 |
| 2 | 0.0068 | 0.0021 | 1,641,194 |
| Average | | | 1,576,918 |

Stress-Strain Curve 140F_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-03-140-FY09
 Test Date: 5/11/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 13,083 lbs
 Shear Stress, S_{xy} : 24,050 psi
 Shear Modulus, G_{xy} : 1,303,147 psi

Measured Specimen Dimensions:

Thickness, T: 0.91 in
 Notch Length, N: 0.60 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,617 lbs
 50% Max Load: 6,542 lbs

PICTURE OF SPECIMEN PRE-TEST



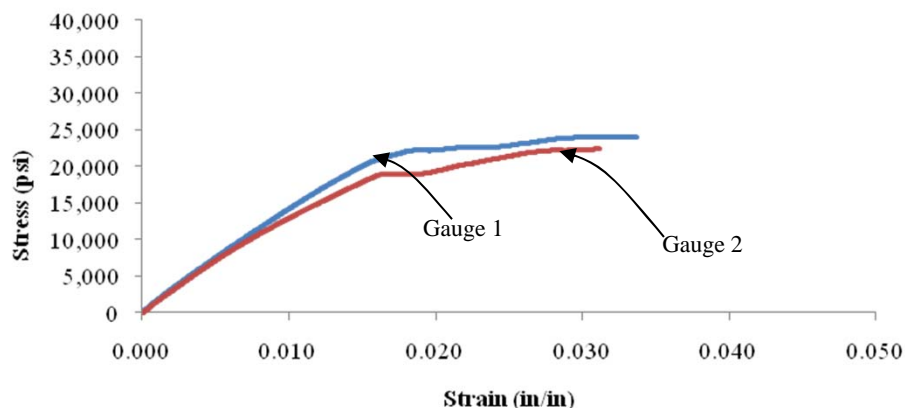
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0083 | 0.0030 | 1,369,760 |
| 2 | 0.0091 | 0.0033 | 1,236,534 |
| Average | | | 1,303,147 |

Stress-Strain Curve 140F_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-04-140-FY09
 Test Date: 5/11/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Ultimate Load, P_{max} : 12,280 lbs
 Shear Stress, S_{xy} : 23,798 psi
 Shear Modulus, G_{xy} : 1,478,597 psi

Measured Specimen Dimensions:

Thickness, T: 0.92 in
 Notch Length, N: 0.56 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,456 lbs
 50% Max Load: 6,140 lbs

PICTURE OF SPECIMEN PRE-TEST



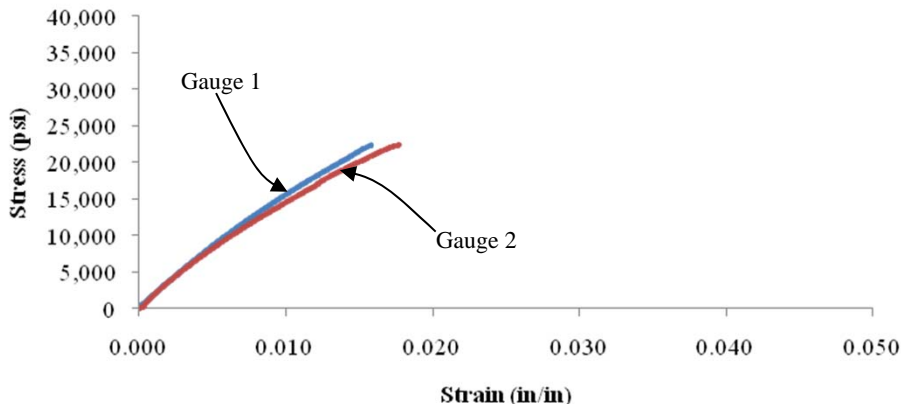
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0072 | 0.0026 | 1,552,641 |
| 2 | 0.0078 | 0.0027 | 1,404,552 |
| Average | | | 1,478,597 |

Stress-Strain Curve 140F_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXY-05-140-FY09
 Test Date: 5/11/2011
 Specimen Received: 3/1/2011
 Properties Measured: S_{xy} , G_{xy}

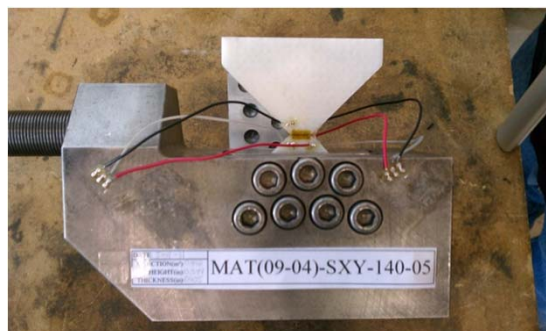
Average Material Properties:

Ultimate Load, P_{max} : 13,047 lbs
 Shear Stress, S_{xy} : 26,519 psi
 Shear Modulus, G_{xy} : 1,397,929 psi

Measured Specimen Dimensions:

Thickness, T: 0.91 in
 Notch Length, N: 0.54 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,609 lbs
 50% Max Load: 6,524 lbs

PICTURE OF SPECIMEN PRE-TEST



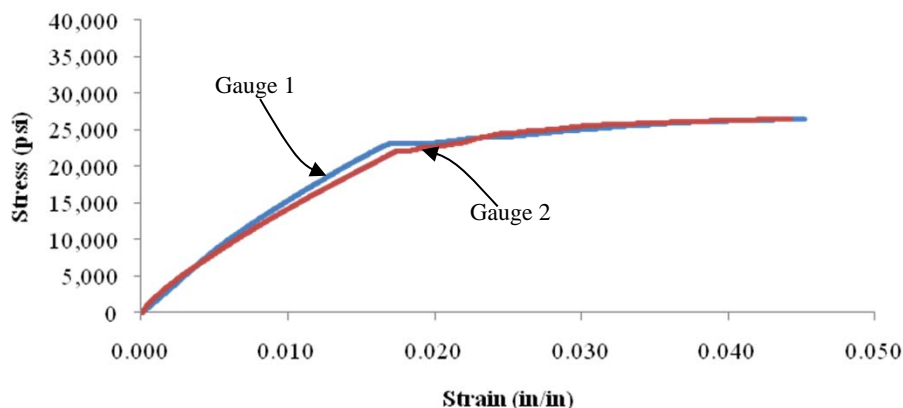
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.0084 | 0.0031 | 1,517,974 |
| 2 | 0.0092 | 0.0029 | 1,277,884 |
| Average | | | 1,397,929 |

Stress-Strain Curve 140F_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

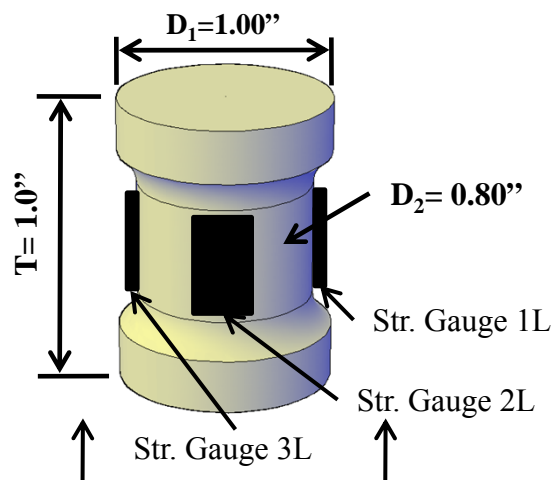
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-TZ-N40-FY09
Material: Huntsman Epoxy Resin SC-15, S2 Glass
Nominal Temperature: -40°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 670 lbs
 Tensile Strength, ST_z : 1,321 psi
 Tensile Modulus, E_z : 1,639,149 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT4-TZ-1-N40-FY09 | 552 | 1,109 | 1,513,500 | Rupture |
| MAT4-TZ-2-N40-FY09 | 695 | 1,236 | 1,875,284 | Rupture |
| MAT4-TZ-3-N40-FY09 | 795 | 1,598 | 1,362,791 | Rupture |
| MAT4-TZ-4-N40-FY09 | 636 | 1,652 | 1,608,584 | Rupture |
| MAT4-TZ-5-N40-FY09 | 670 | 1,262 | 1,835,583 | Rupture |
| Average | 670 | 1,371 | 1,639,149 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-56 to G-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-1-N40-FY09**
 Test Date: 6/17/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

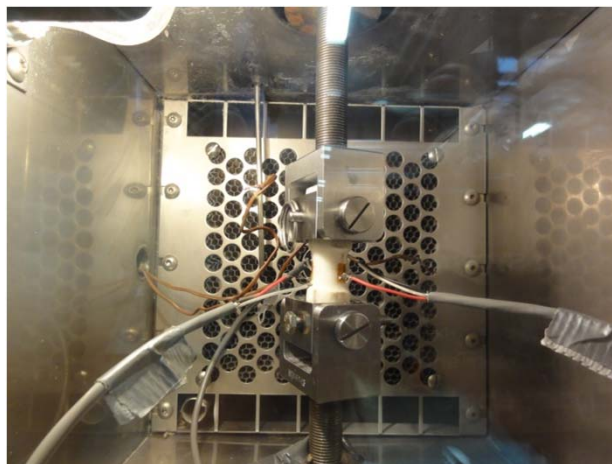
Average Material Properties:

Tensile Strength, ST_z : 1,109 psi
 Tensile Modulus, E_z : 1,513,500 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.796 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 554 psi
 20% Max Stress: 222 psi

PICTURE OF SPECIMEN PRE-TEST



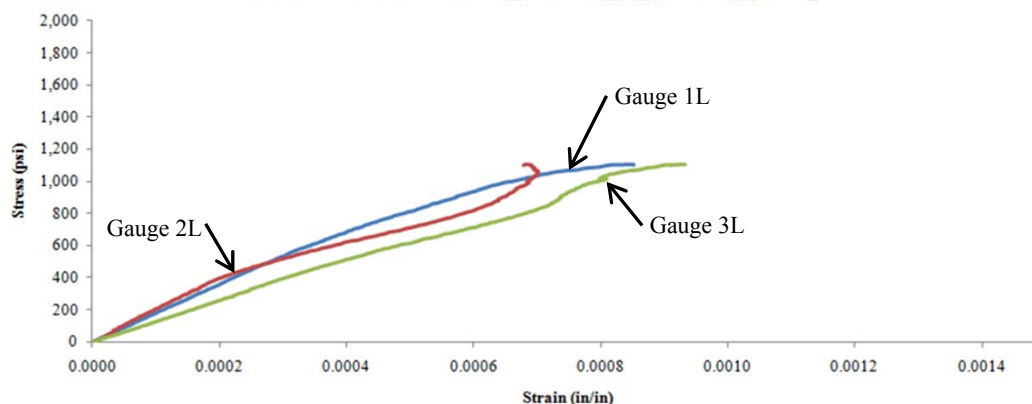
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000308 | 0.000122 | 1,782,483 |
| 2L | 0.000330 | 0.000108 | 1,494,668 |
| 3L | 0.000434 | 0.000171 | 1,263,350 |
| Average | | | 1,513,500 |

Stress-Strain Curve_N40°F_1_(09-04)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-2-N40-FY09**
 Test Date: 6/20/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

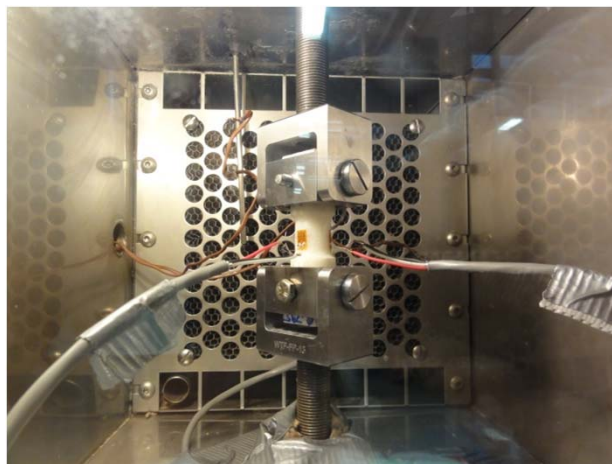
Average Material Properties:

Tensile Strength, ST_z : 1,236 psi
 Tensile Modulus, E_z : 1,441,732 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.050 in
 Diameter, D_2 : 0.846 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 618 psi
 20% Max Stress: 247 psi

PICTURE OF SPECIMEN PRE-TEST



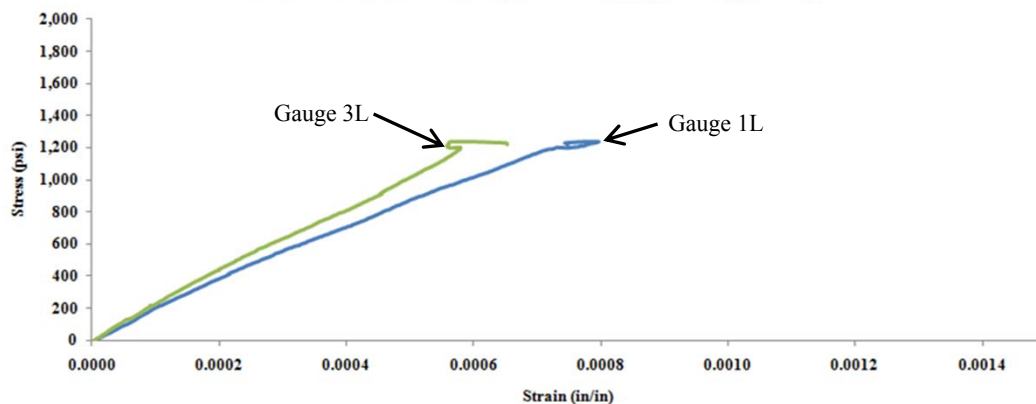
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000339 | 0.000123 | 1,718,220 |
| 2L | Lost Gauge | | |
| 3L | 0.000291 | 0.000108 | 2,032,349 |
| Average | | | 1,875,284 |

Stress-Strain Curve_N40°F_2_(09-04)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-3-N40-FY09**
 Test Date: 6/20/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,598 psi
 Tensile Modulus, E_z : 1,362,791 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.996 in
 Diameter, D_2 : 0.796 in

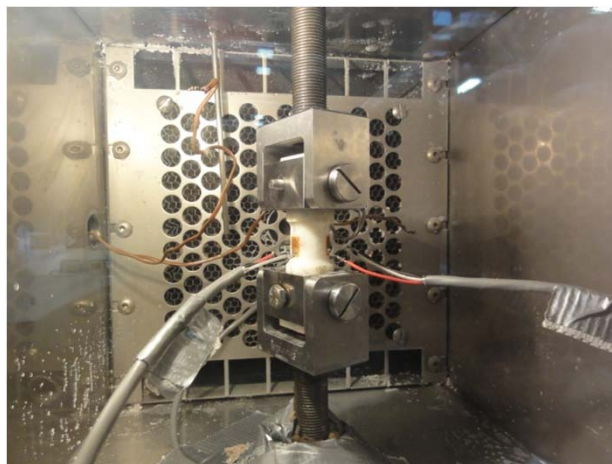
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 799 psi

20% Max Stress: 320 psi

PICTURE OF SPECIMEN PRE-TEST



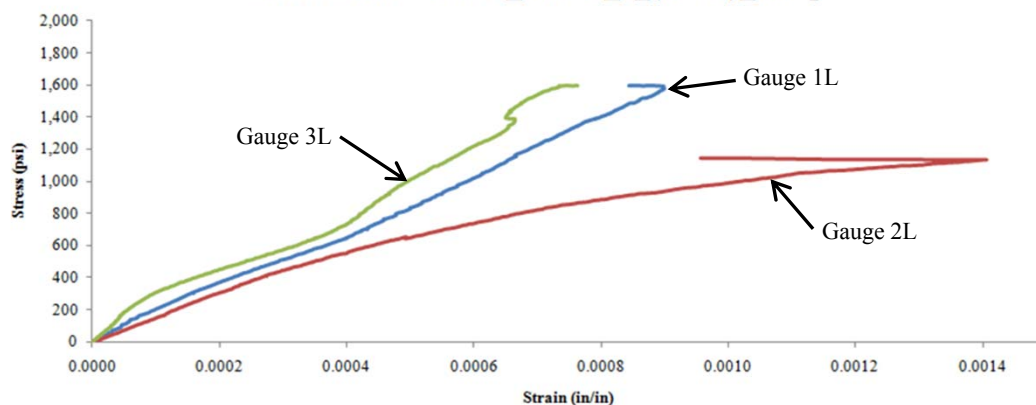
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000477 | 0.000163 | 1,529,522 |
| 2L | 0.000672 | 0.000211 | 1,039,095 |
| 3L | 0.000421 | 0.000106 | 1,519,755 |
| Average | | | 1,362,791 |

Stress-Strain Curve_N40°F_3_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-4-N40-FY09**
 Test Date: 6/20/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

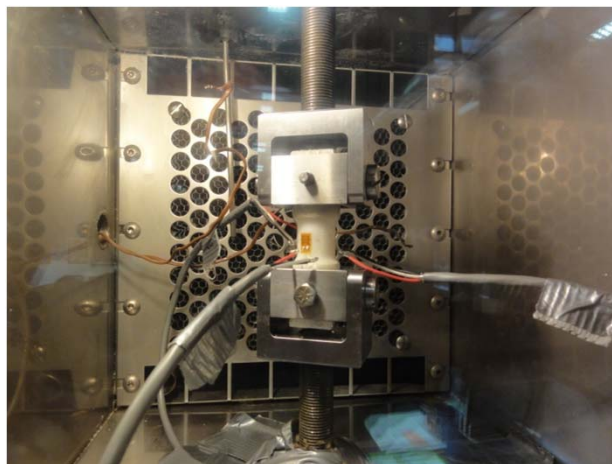
Average Material Properties:

Tensile Strength, ST_z : 1,652 psi
 Tensile Modulus, E_z : 1,608,584 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.903 in
 Diameter, D_2 : 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 826 psi
 20% Max Stress: 330 psi

PICTURE OF SPECIMEN PRE-TEST



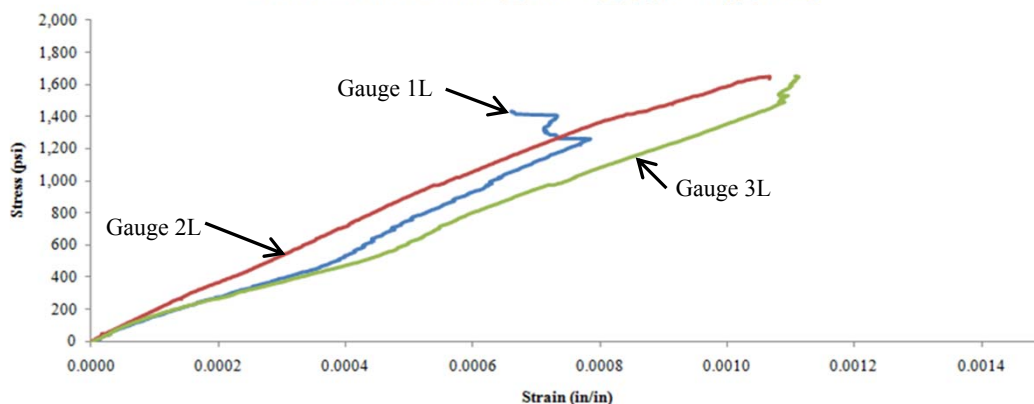
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000539 | 0.000245 | 1,683,188 |
| 2L | 0.000456 | 0.000175 | 1,764,362 |
| 3L | 0.000617 | 0.000257 | 1,378,202 |
| Average | | | 1,608,584 |

Stress-Strain Curve_N40°F_4_(09-04)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-5-N40-FY09**
 Test Date: 6/21/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

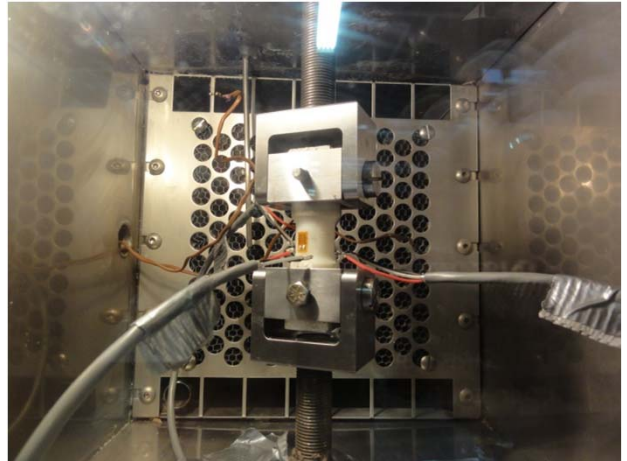
Average Material Properties:

Tensile Strength, ST_z : 1,262 psi
 Tensile Modulus, E_z : 1,835,583 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.030 in
 Diameter, D_2 : 0.822 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 631 psi
 20% Max Stress: 252 psi

PICTURE OF SPECIMEN PRE-TEST



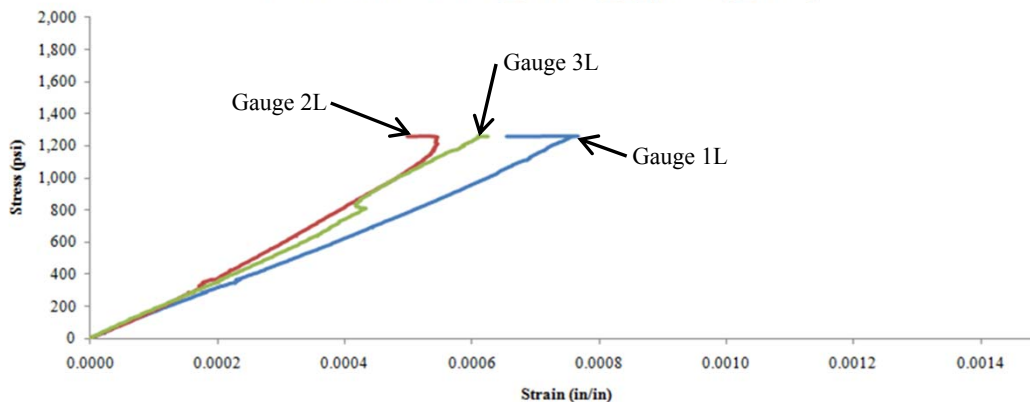
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000404 | 0.000158 | 1,544,339 |
| 2L | 0.000317 | 0.000141 | 2,152,834 |
| 3L | 0.000349 | 0.000140 | 1,809,578 |
| Average | | | 1,835,583 |

Stress-Strain Curve_N40°F_5_(09-04)_Long



Engineering Test notes:

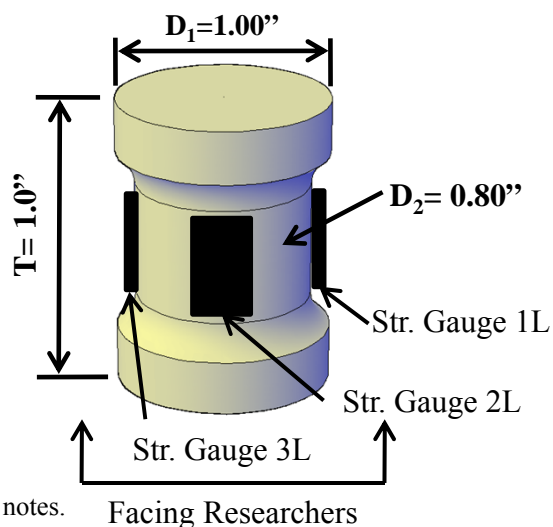
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT4-TZ-70-FY09**Material:** SC-15, S2 Glass**Nominal Temperature:** 70°F**Properties Measured:** ST_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 741 lbs**Tensile Strength, ST_z :** 1,481 psi**Tensile Modulus, E_z :** 1,603,490 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT4-TZ-1-70-FY09 | 976 | 1,848 | 1,681,581 | Rupture |
| MAT4-TZ-2-70-FY09 | 577 | 1,079 | 1,454,678 | Rupture |
| MAT4-TZ-3-70-FY09 | 600 | 1,453 | 1,671,728 | Rupture |
| MAT4-TZ-4-70-FY09 | 701 | 1,327 | 1,684,757 | Rupture |
| MAT4-TZ-5-70-FY09 | 852 | 1,700 | 1,524,705 | Rupture |
| Average | 741 | 1,481 | 1,603,490 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-62 to G-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-1-70-FY09**
 Test Date: 6/22/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,848 psi
 Tensile Modulus, E_z : 1,681,581 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.020 in
 Diameter, D_2 : 0.820 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 924 psi

20% Max Stress: 370 psi

PICTURE OF SPECIMEN PRE-TEST

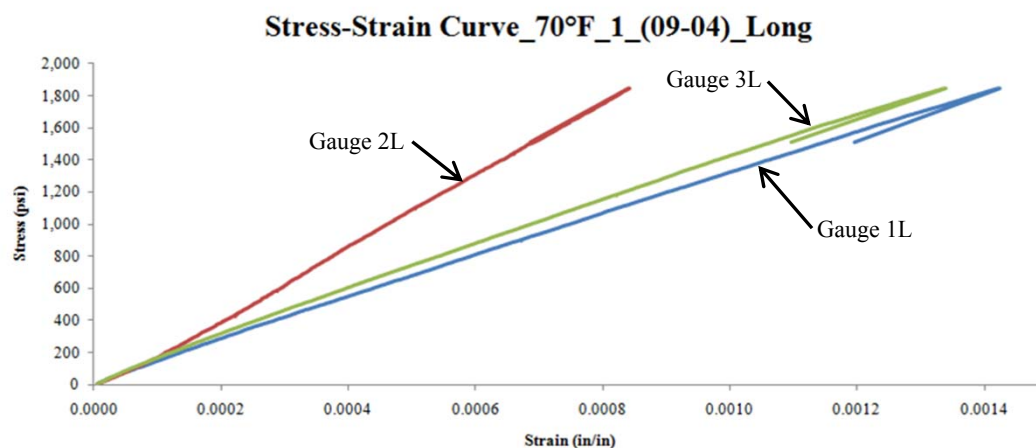


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000685 | 0.000256 | 1,292,122 |
| 2L | 0.000426 | 0.000191 | 2,353,947 |
| 3L | 0.000629 | 0.000232 | 1,398,674 |
| Average | | | 1,681,581 |



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-2-70-FY09**
 Test Date: 6/22/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,079 psi
 Tensile Modulus, E_z : 1,454,678 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.025 in
 Diameter, D_2 : 0.825 in

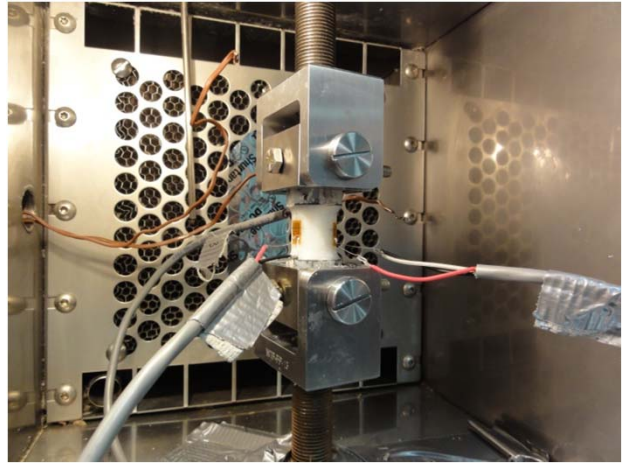
Laboratory Temperature: 68°F

Failure Mode: Rupture

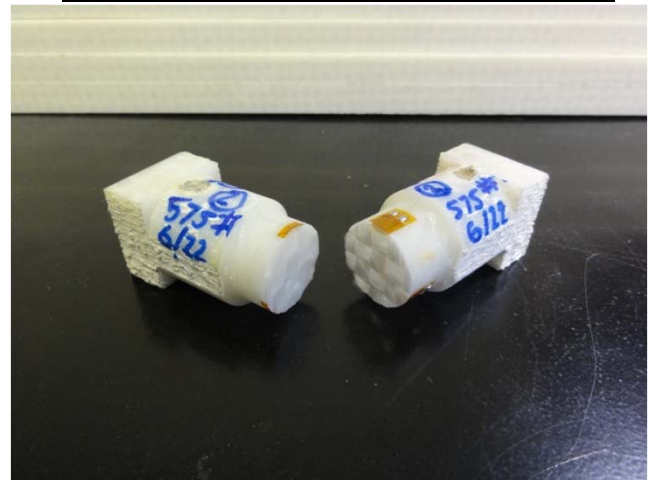
50% Max Stress: 540 psi

20% Max Stress: 216 psi

PICTURE OF SPECIMEN PRE-TEST



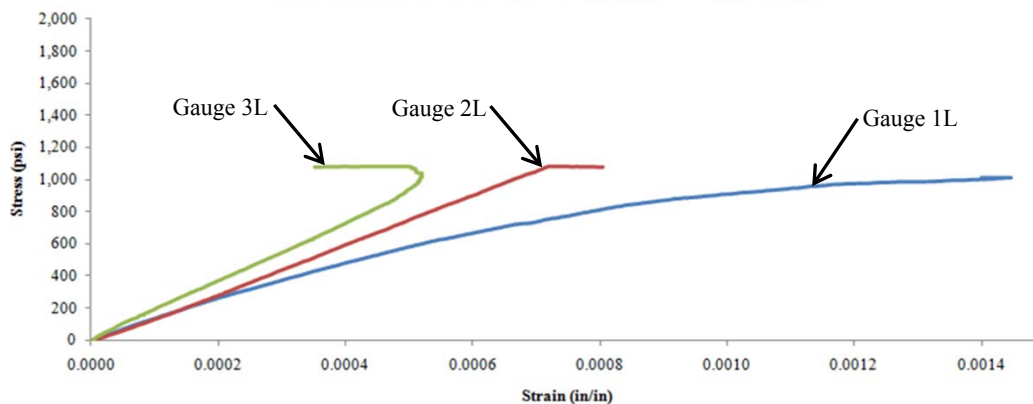
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000456 | 0.000159 | 1,089,731 |
| 2L | 0.000367 | 0.000157 | 1,542,478 |
| 3L | 0.000297 | 0.000110 | 1,731,824 |
| Average | | | 1,454,678 |

Stress-Strain Curve_70°F_2_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-3-70-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,453 psi
 Tensile Modulus, E_z : 1,671,728 psi

Measured Specimen Dimensions:

Diameter, D_1 : 0.925 in
 Diameter, D_2 : 0.725 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

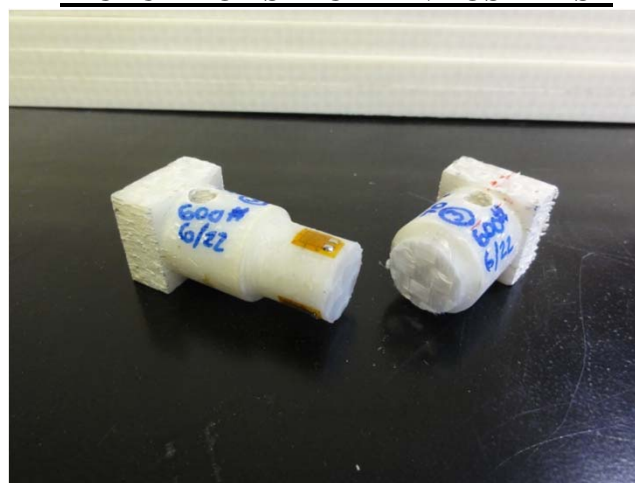
50% Max Stress: 727 psi

20% Max Stress: 291 psi

PICTURE OF SPECIMEN PRE-TEST



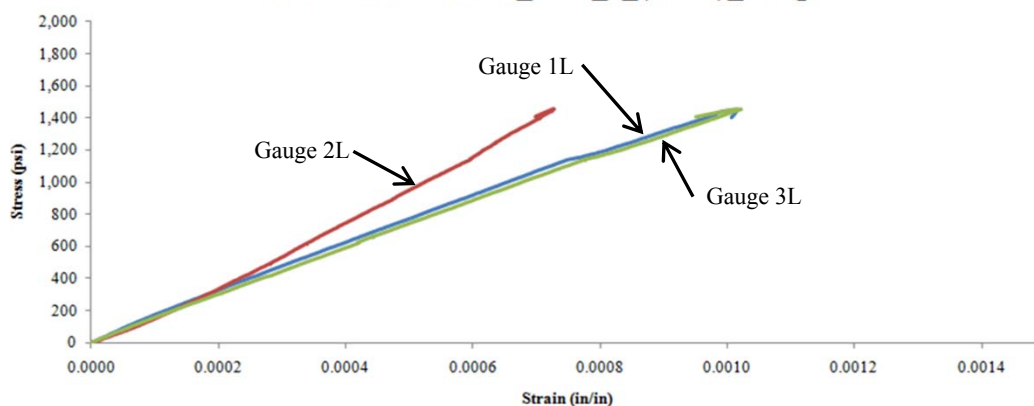
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000465 | 0.000174 | 1,498,473 |
| 2L | 0.000390 | 0.000177 | 2,046,522 |
| 3L | 0.000486 | 0.000190 | 1,470,189 |
| Average | | | 1,671,728 |

Stress-Strain Curve_70°F_3_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-4-70-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,327 psi
 Tensile Modulus, E_z : 1,684,757 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.028 in
 Diameter, D_2 : 0.820 in

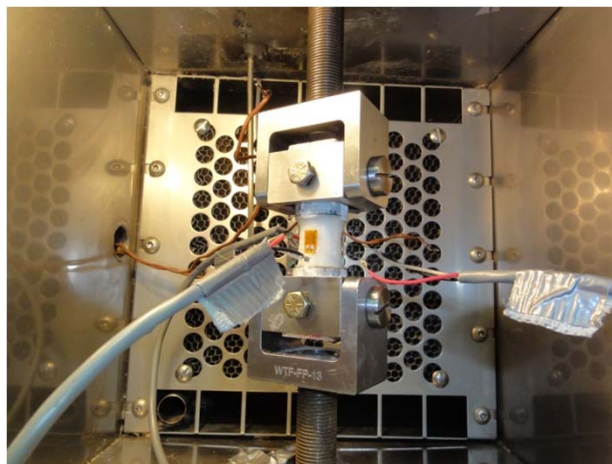
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 663 psi

20% Max Stress: 265 psi

PICTURE OF SPECIMEN PRE-TEST



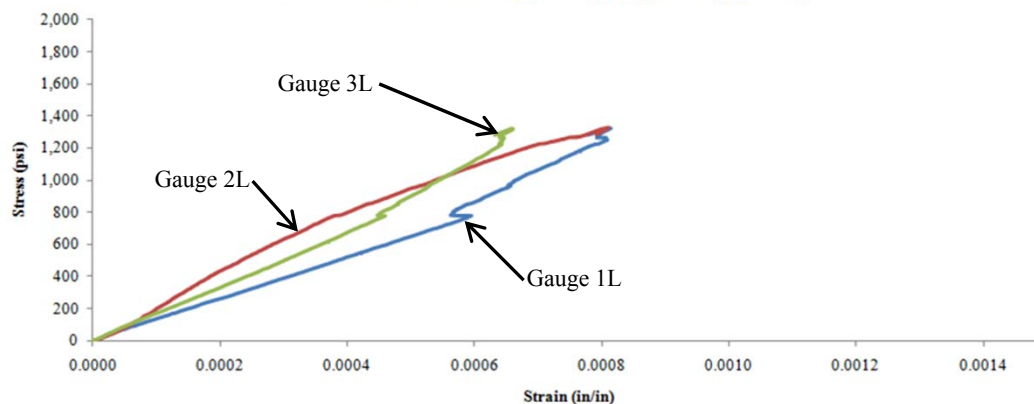
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000508 | 0.000201 | 1,293,649 |
| 2L | 0.000318 | 0.000125 | 2,071,195 |
| 3L | 0.000393 | 0.000158 | 1,689,426 |
| Average | | | 1,684,757 |

Stress-Strain Curve_70°F_4_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-5-70-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,700 psi
 Tensile Modulus, E_z : 1,524,705 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.027 in
 Diameter, D_2 : 0.825 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 850 psi

20% Max Stress: 340 psi

PICTURE OF SPECIMEN PRE-TEST



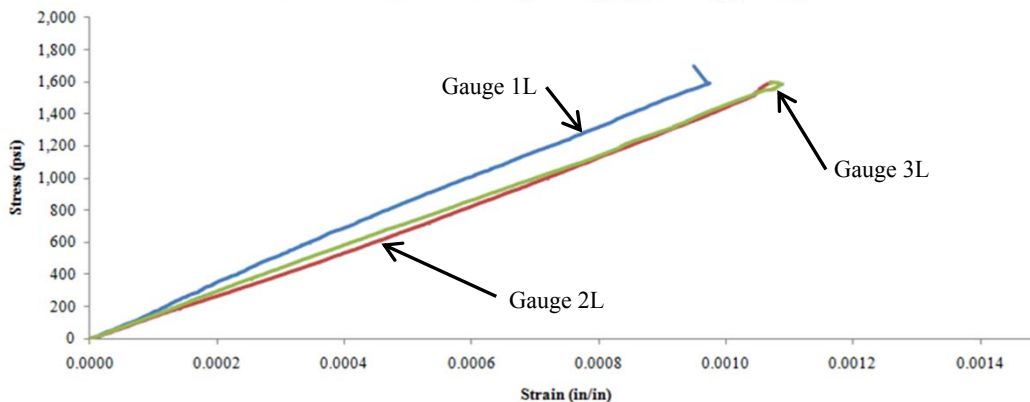
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000489 | 0.000192 | 1,714,818 |
| 2L | 0.000610 | 0.000254 | 1,432,340 |
| 3L | 0.000583 | 0.000225 | 1,426,957 |
| Average | | | 1,524,705 |

Stress-Strain Curve_70°F_5_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

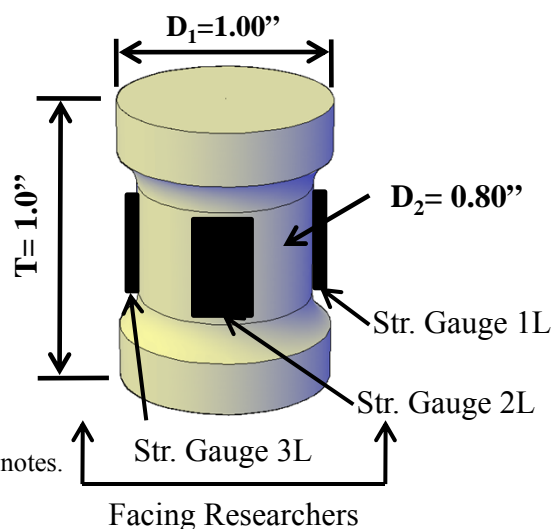
*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT4-TZ-140-FY09**Material:** SC-15, S2 Glass**Nominal Temperature:** 140°F**Properties Measured:** ST_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 644 lbs**Tensile Strength, ST_z :** 1,215 psi**Tensile Modulus, E_z :** 1,291,607 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT4-TZ-1-140-FY09 | 692 | 1,298 | 1,058,410 | Bondline |
| MAT4-TZ-2-140-FY09 | 661 | 1,253 | 1,398,506 | Bondline |
| MAT4-TZ-3-140-FY09 | 696 | 1,318 | 1,321,374 | Rupture |
| MAT4-TZ-4-140-FY09 | 615 | 1,164 | 1,306,549 | Rupture |
| MAT4-TZ-5-140-FY09 | 557 | 1,042 | 1,373,194 | Rupture |
| Average | 644 | 1,215 | 1,291,607 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-68 to G-72 for individual specimen test summary sheets and notes.
- 2) Bondline failure indicates ASTM failure at less than 1 ply away from the epoxied bondline at the base of the specimen.
- 3) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-1-140-FY09**
 Test Date: 6/21/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,298 psi
 Tensile Modulus, E_z : 1,058,410 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.028 in
 Diameter, D_2 : 0.824 in

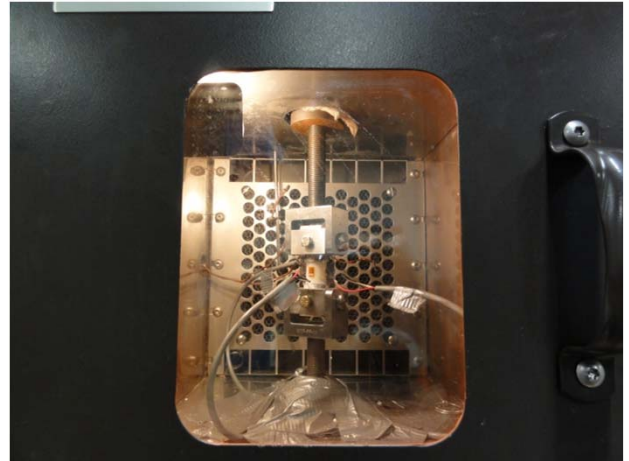
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Stress: 649 psi

20% Max Stress: 260 psi

PICTURE OF SPECIMEN PRE-TEST



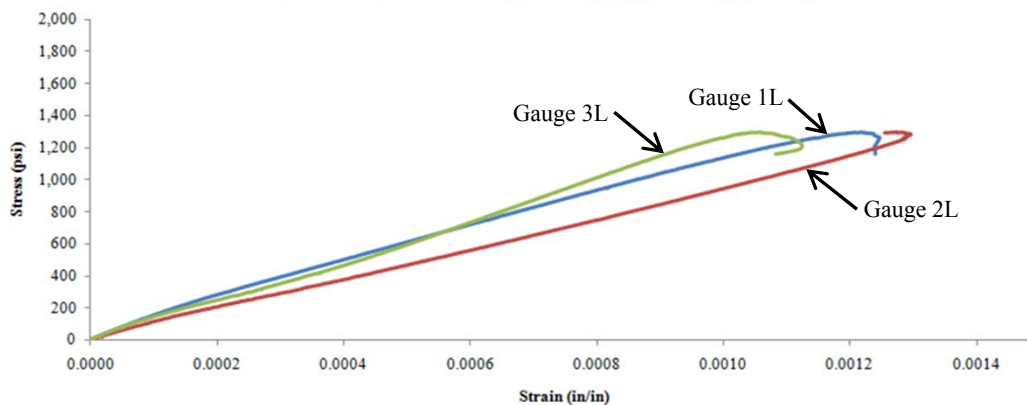
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000534 | 0.000179 | 1,097,769 |
| 2L | 0.000695 | 0.000260 | 894,991 |
| 3L | 0.000539 | 0.000210 | 1,182,471 |
| Average | | | 1,058,410 |

Stress-Strain Curve_140°F_1_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-2-140-FY09**
 Test Date: 6/22/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,253 psi
 Tensile Modulus, E_z : 1,398,506 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.022 in
 Diameter, D_2 : 0.820 in

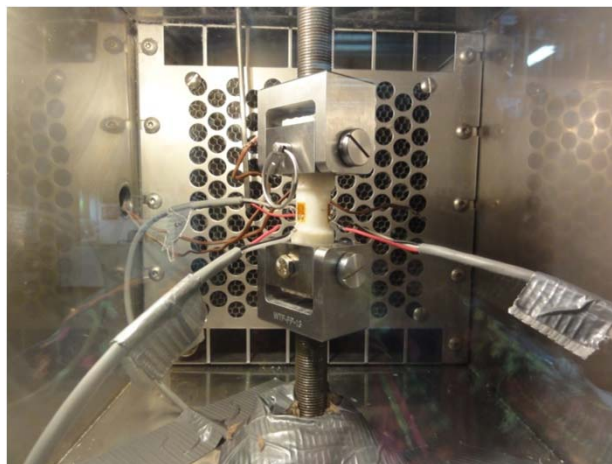
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Stress: 626 psi

20% Max Stress: 251 psi

PICTURE OF SPECIMEN PRE-TEST



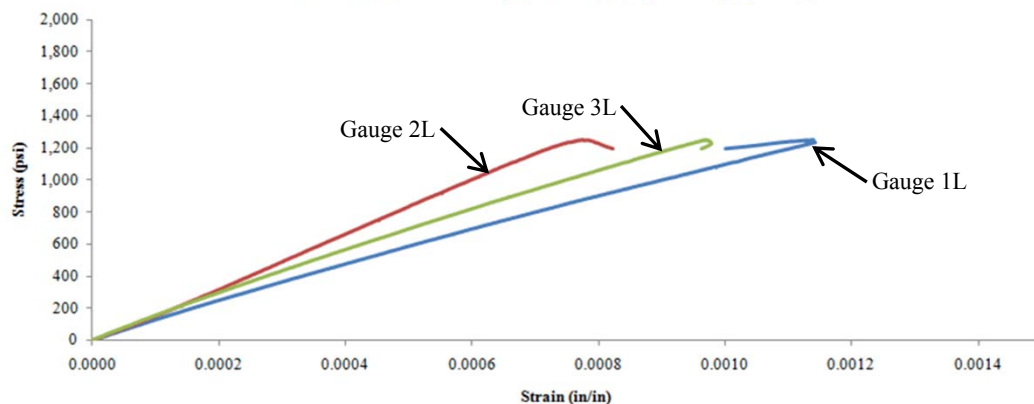
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000534 | 0.000200 | 1,123,870 |
| 2L | 0.000377 | 0.000160 | 1,725,077 |
| 3L | 0.000444 | 0.000165 | 1,346,571 |
| Average | | | 1,398,506 |

Stress-Strain Curve_140°F_2_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-3-140-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

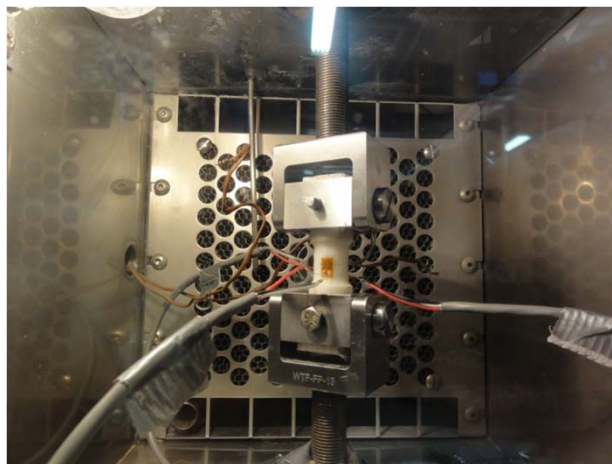
Average Material Properties:

Tensile Strength, ST_z : 1,318 psi
 Tensile Modulus, E_z : 1,321,374 psi

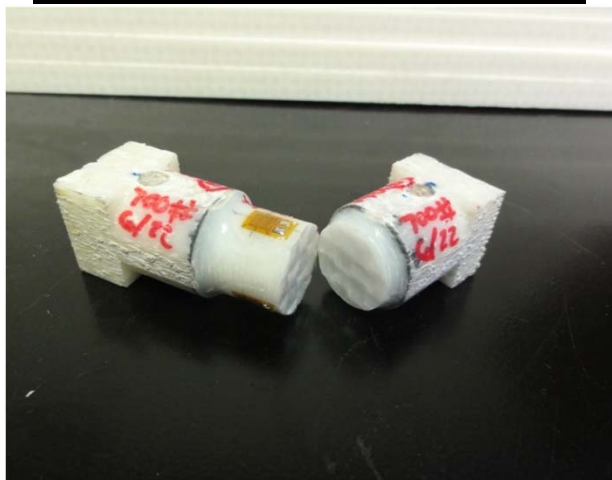
Measured Specimen Dimensions:

Diameter, D_1 : 1.020 in
 Diameter, D_2 : 0.820 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 659 psi
 20% Max Stress: 264 psi

PICTURE OF SPECIMEN PRE-TEST



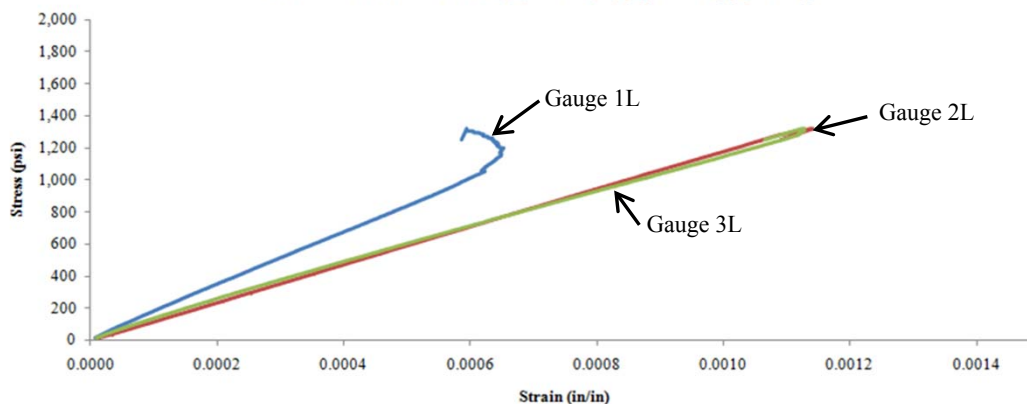
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000390 | 0.000148 | 1,634,236 |
| 2L | 0.000558 | 0.000226 | 1,191,240 |
| 3L | 0.000551 | 0.000204 | 1,138,646 |
| Average | | | 1,321,374 |

Stress-Strain Curve_140°F_3_(09-04)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-4-140-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 1,164 psi
 Tensile Modulus, E_z : 1,306,549 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.026 in
 Diameter, D_2 : 0.820 in

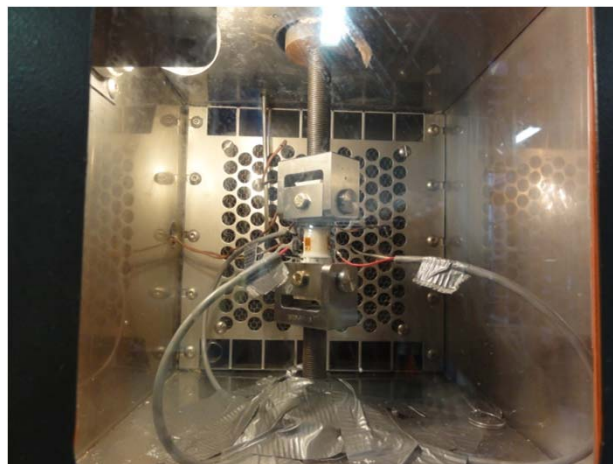
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Stress: 582 psi

20% Max Stress: 233 psi

PICTURE OF SPECIMEN PRE-TEST



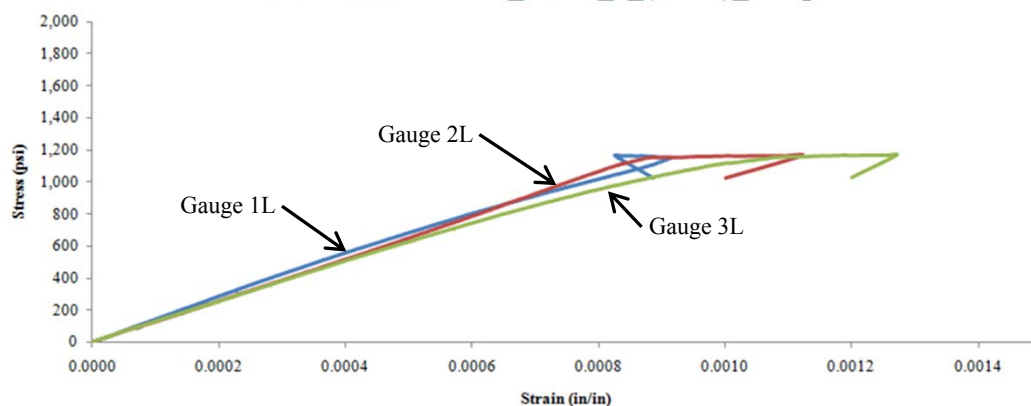
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000417 | 0.000162 | 1,366,694 |
| 2L | 0.000448 | 0.000180 | 1,304,936 |
| 3L | 0.000463 | 0.000183 | 1,248,018 |
| Average | | | 1,306,549 |

Stress-Strain Curve_140°F_4_(09-04)_Long



Engineering Test notes:

*Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.

*Elastic Modulus was calculated using strain at 20% and 50% of max load

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-TZ-5-140-FY09**
 Test Date: 6/23/2011
 Specimen Received: 5/27/2011
 Properties Measured: ST_z , E_z

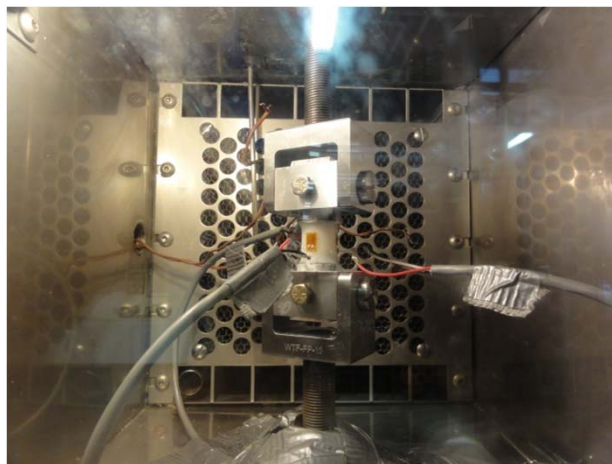
Average Material Properties:

Tensile Strength, ST_z : 1,042 psi
 Tensile Modulus, E_z : 1,373,194 psi

Measured Specimen Dimensions:

Diameter, D_1 : 1.031 in
 Diameter, D_2 : 0.825 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 521 psi
 20% Max Stress: 208 psi

PICTURE OF SPECIMEN PRE-TEST



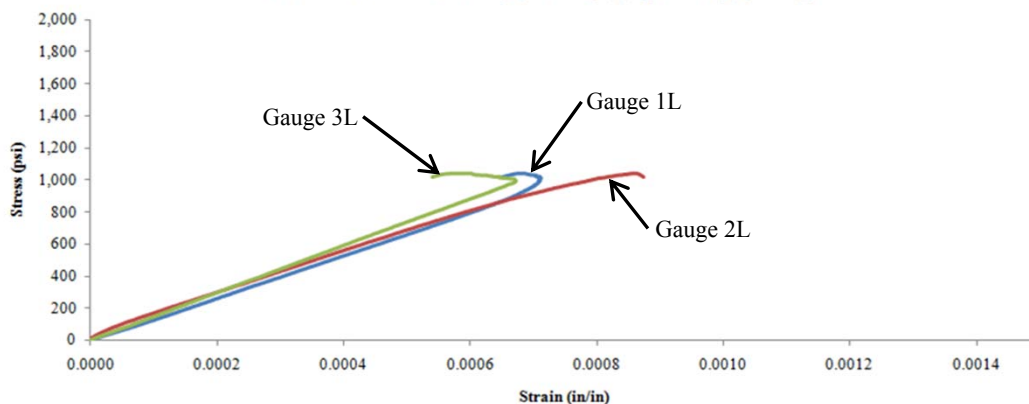
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.000395 | 0.000161 | 1,338,005 |
| 2L | 0.000369 | 0.000128 | 1,299,403 |
| 3L | 0.000351 | 0.000140 | 1,482,175 |
| Average | | | 1,373,194 |

Stress-Strain Curve_140°F_5_(09-04)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CZ-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 56,411 lbs

Compressive Strength, SC_z : 100,873 psi

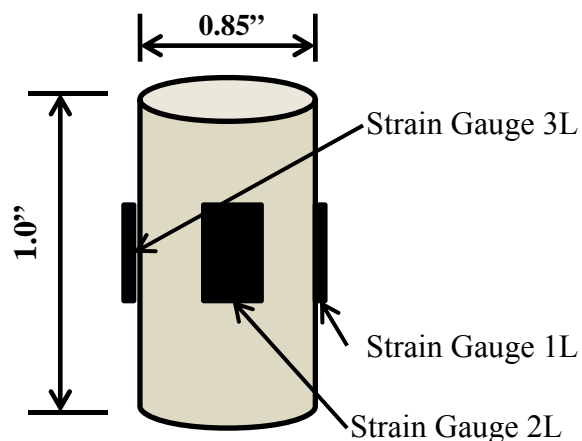
Compressive Modulus, E_z : 1,831,220 psi

Ultimate Strain, ϵ_z : 0.055 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT4-CZ-01-N40-FY09 | 55,611 | 100,380 | 1,780,002 | 0.057 | Rupture |
| MAT4-CZ-02-N40-FY09 | 55,715 | 99,669 | 1,800,606 | 0.055 | Rupture |
| MAT4-CZ-03-N40-FY09 | 55,352 | 100,094 | 1,748,076 | 0.058 | Rupture |
| MAT4-CZ-04-N40-FY09 | 57,244 | 100,960 | 1,982,204 | 0.051 | Rupture |
| MAT4-CZ-05-N40-FY09 | 58,135 | 103,260 | 1,845,213 | 0.056 | Rupture |
| Average | 56,411 | 100,873 | 1,831,220 | 0.055 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for the Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-74 to G-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-01-N40-FY09**
 Test Date: 6/10/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 55,611 lbs
 Maximum Stress, SC_z : 100,380 psi
 Elastic Modulus, E_z : 1,780,002 psi
 Ultimate Strain, ϵ_z : 0.057 in/in

Measured Specimen Dimensions:

Length, L: 1.02 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,122 psi
 50% Max Load: 27,805 psi

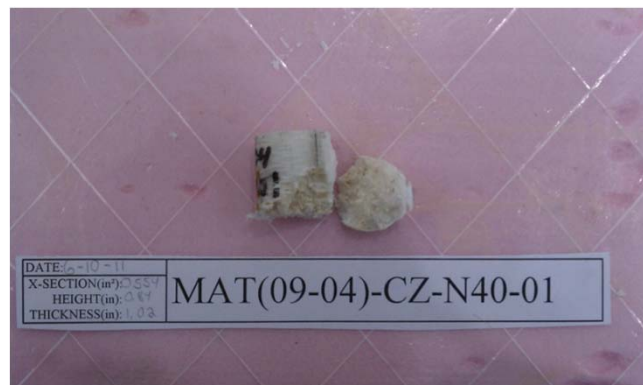
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0290 | -0.0129 | 1,870,396 |
| 2L | -0.0291 | -0.0108 | 1,639,827 |
| 3L | -0.0238 | -0.0073 | 1,829,784 |
| Average | | | 1,780,002 |

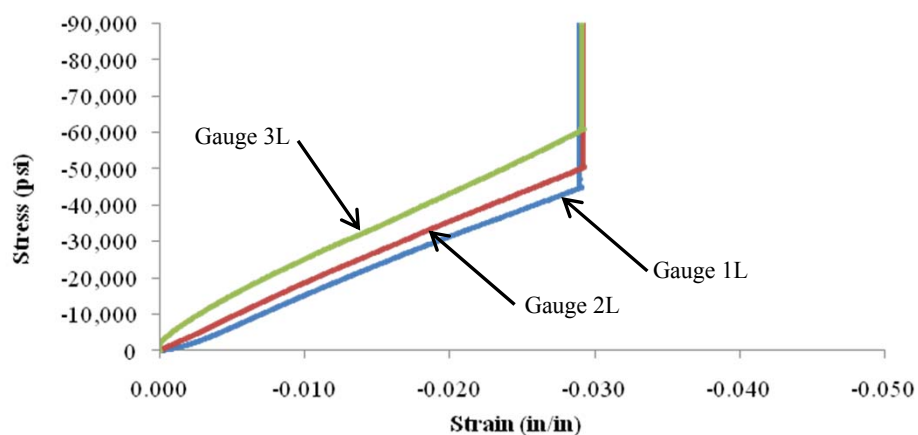
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-02-N40-FY09**
 Test Date: 6/10/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 55,715 lbs
 Maximum Stress, SC_z : 99,669 psi
 Elastic Modulus, E_z : 1,800,606 psi
 Ultimate Strain, ϵ_z : 0.055 in/in

Measured Specimen Dimensions:

Length, L: 1.02 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,143 psi
 50% Max Load: 27,858 psi

PICTURE OF SPECIMEN PRE-TEST



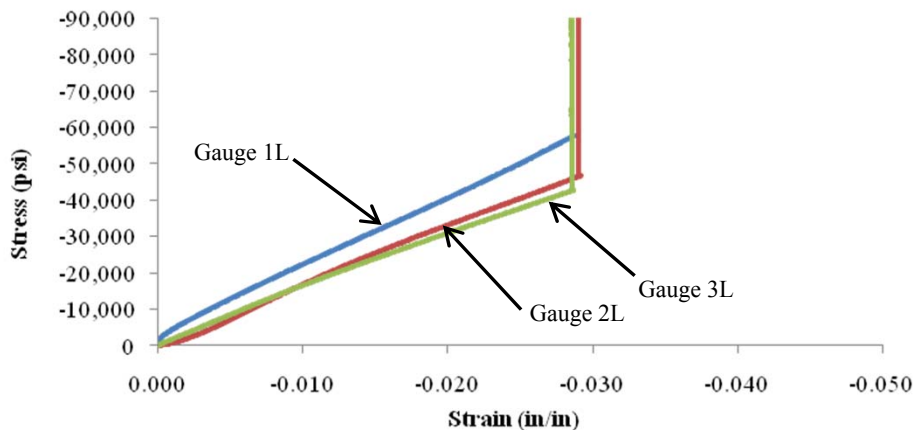
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0249 | -0.0087 | 1,846,087 |
| 2L | -0.0291 | -0.0117 | 1,723,991 |
| 3L | -0.0286 | 0.0122 | 1,831,740 |
| Average | | | 1,800,606 |

Stress-Strain Curve N40_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-03-N40-FY09**
 Test Date: 6/10/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 55,352 lbs
 Maximum Stress, SC_z : 100,094 psi
 Elastic Modulus, E_z : 1,748,076 psi
 Ultimate Strain, ϵ_z : 0.058 in/in

Measured Specimen Dimensions:

Length, L: 1.03 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,070 psi
 50% Max Load: 27,676 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0271 | -0.0088 | 1,638,822 |
| 2L | -0.0288 | -0.0091 | 1,521,054 |
| 3L | -0.0287 | -0.0143 | 2,084,351 |
| Average | | | 1,745,076 |

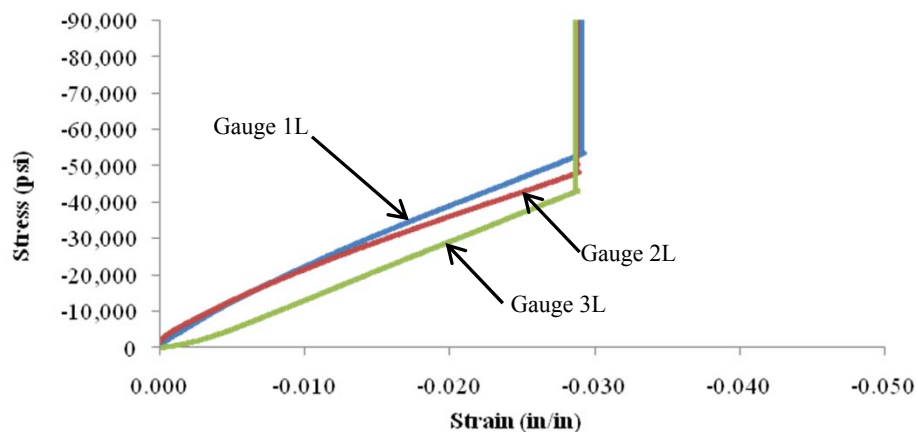
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-04-N40-FY09**
 Test Date: 6/13/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 57,244 lbs
 Maximum Stress, SC_z : 100,960 psi
 Elastic Modulus, E_z : 1,982,204 psi
 Ultimate Strain, ϵ_z : 0.051 in/in

Measured Specimen Dimensions:

Length, L: 1.01 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,449 psi
 50% Max Load: 28,622 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0216 | -0.0069 | 2,068,263 |
| 2L | -0.0283 | -0.0124 | 1,907,018 |
| 3L | -0.0234 | -0.0081 | 1,971,332 |
| Average | | | 1,982,204 |

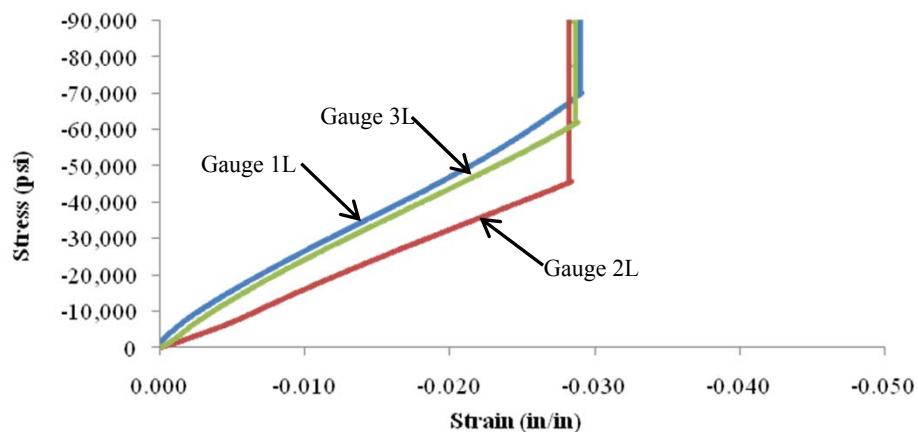
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-05-N40-FY09**
 Test Date: 6/13/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 58,135 lbs
 Maximum Stress, SC_z : 103,260 psi
 Elastic Modulus, E_z : 1,845,213 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured Specimen Dimensions:

Length, L: 1.01 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,627 psi
 50% Max Load: 29,068 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0279 | -0.0126 | 2,026,846 |
| 2L | -0.0272 | -0.0093 | 1,728,926 |
| 3L | -0.0284 | -0.0110 | 1,779,865 |
| Average | | | 1,845,213 |

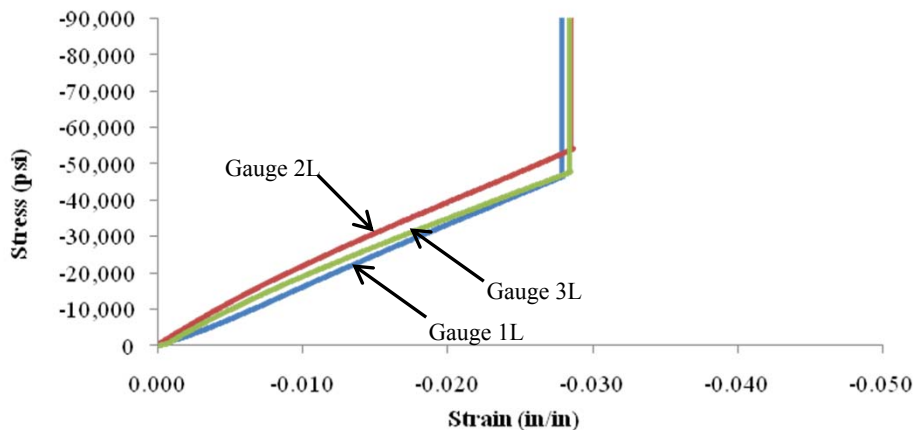
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

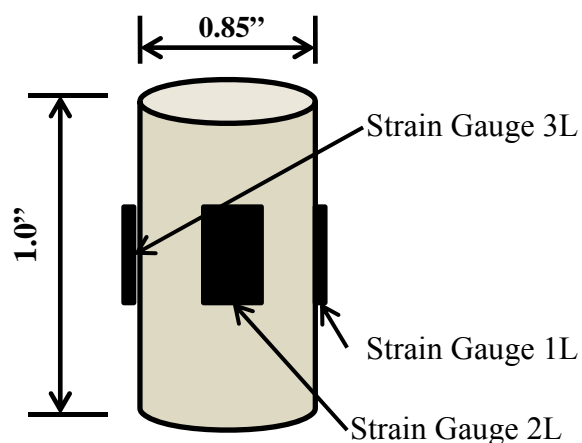
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CZ-70-FY09
 Material: SC-15, S2 Glass
 Nominal Temperature: 70°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 44,516 lbs
 Compressive Strength, SC_z : 79,906 psi
 Compressive Modulus, E_z : 1,345,276 psi
 Ultimate Strain, ϵ_z : 0.060 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT4-CZ-01-70-FY09 | 43,966 | 78,651 | 1,282,884 | 0.062 | Rupture |
| MAT4-CZ-02-70-FY09 | 42,409 | 75,596 | 1,320,181 | 0.058 | Rupture |
| MAT4-CZ-03-70-FY09 | 44,686 | 80,516 | 1,273,192 | 0.063 | Rupture |
| MAT4-CZ-04-70-FY09 | 45,853 | 83,368 | 1,506,171 | 0.056 | Rupture |
| MAT4-CZ-05-70-FY09 | 45,666 | 81,400 | 1,343,951 | 0.061 | Rupture |
| Average | 44,516 | 79,906 | 1,345,276 | 0.060 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- Reference G-80 to G-84 for individual specimen test summary sheets and notes.
- The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-01-70-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 43,966 lbs
 Maximum Stress, SC_z : 78,651 psi
 Elastic Modulus, E_z : 1,282,884 psi
 Ultimate Strain, ϵ_z : 0.062 in/in

Measured Specimen Dimensions:

Length, L: 1.02 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,793 psi
 50% Max Load: 21,983 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0284 | -0.0088 | 1,202,819 |
| 2L | -0.0257 | -0.0091 | 1,415,559 |
| 3L | -0.0302 | -0.0110 | 1,230,273 |
| Average | | | 1,282,884 |

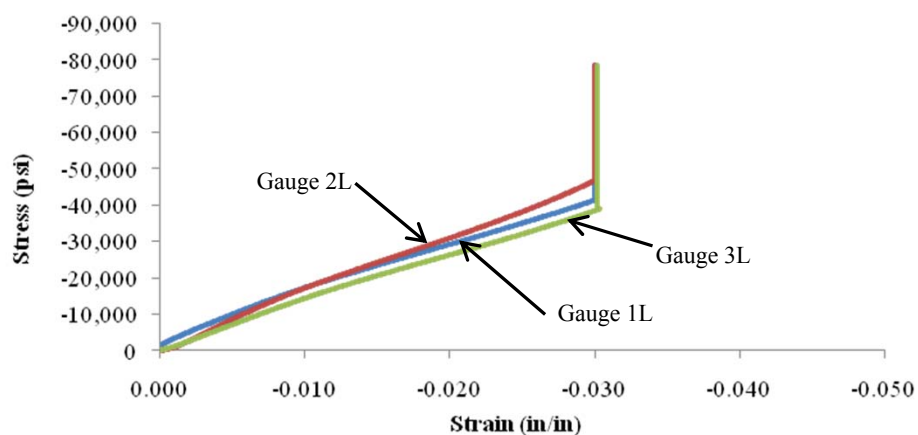
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-02-70-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 42,409 lbs
 Maximum Stress, SC_z : 75,596 psi
 Elastic Modulus, E_z : 1,320,181 psi
 Ultimate Strain, ϵ_z : 0.058 in/in

Measured Specimen Dimensions:

Length, L: 1.00 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,482 psi
 50% Max Load: 21,205 psi

PICTURE OF SPECIMEN PRE-TEST



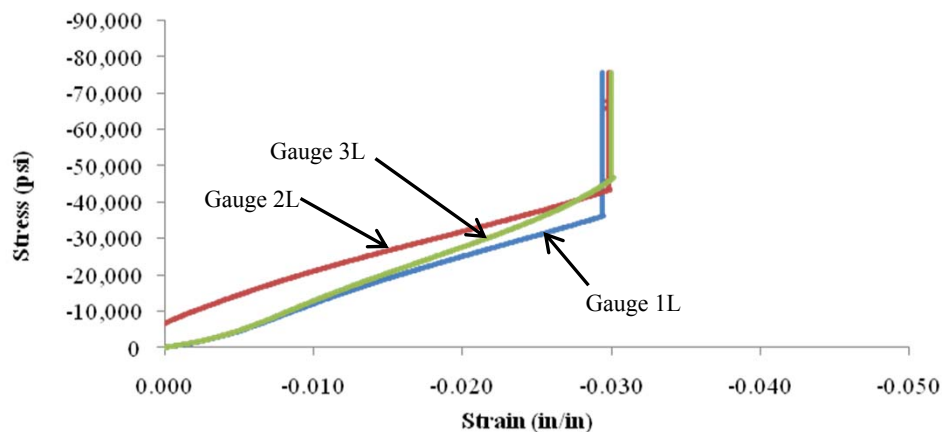
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0294 | -0.0121 | 1,311,102 |
| 2L | -0.0254 | -0.0054 | 1,132,980 |
| 3L | -0.0263 | -0.0114 | 1,516,461 |
| Average | | | 1,320,181 |

Stress-Strain Curve 70F_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-03-70-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 44,686 lbs
 Maximum Stress, SC_z : 80,516 psi
 Elastic Modulus, E_z : 1,273,192 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

Measured Specimen Dimensions:

Length, L: 1.02 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,937 psi
 50% Max Load: 22,343 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0303 | -0.0119 | 1,311,625 |
| 2L | -0.0281 | -0.0074 | 1,164,120 |
| 3L | -0.0278 | -0.0098 | 1,343,829 |
| Average | | | 1,273,192 |

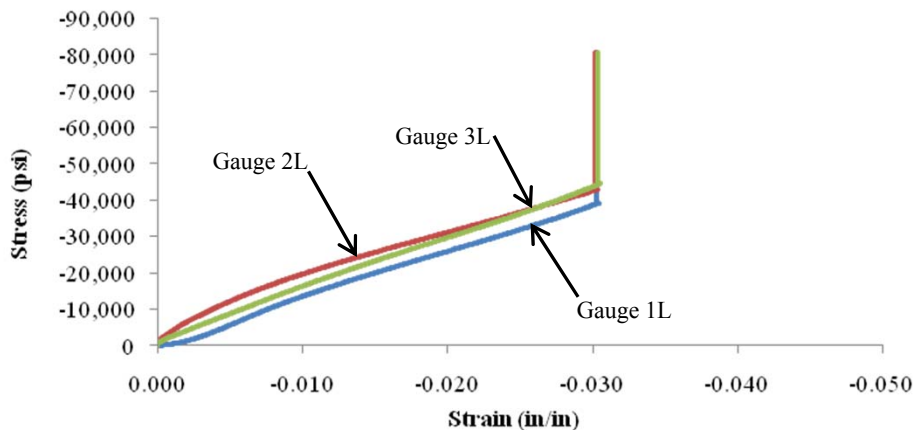
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve_70F_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-04-70-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 45,853 lbs
 Maximum Stress, SC_z : 83,368 psi
 Elastic Modulus, E_z : 1,506,171 psi
 Ultimate Strain, ϵ_z : 0.056 in/in

Measured Specimen Dimensions:

Length, L: 1.00 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,171 psi
 50% Max Load: 22,926 psi

PICTURE OF SPECIMEN PRE-TEST



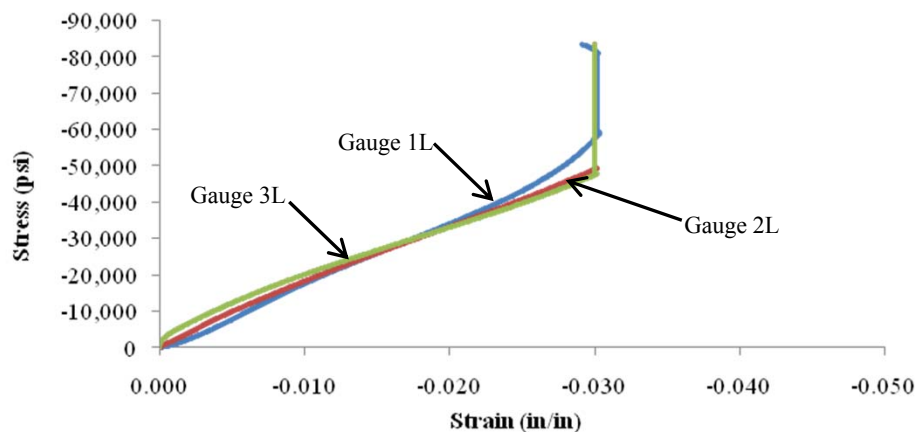
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0243 | -0.0094 | 1,683,441 |
| 2L | -0.0256 | -0.0090 | 1,503,848 |
| 3L | -0.0264 | -0.0076 | 1,331,223 |
| Average | | | 1,506,171 |

Stress-Strain Curve 70F_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-05-70-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 45,666 lbs
 Maximum Stress, SC_z : 81,400 psi
 Elastic Modulus, E_z : 1,343,057 psi
 Ultimate Strain, ϵ_z : 0.061 in/in

Measured Specimen Dimensions:

Length, L: 1.00 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,133 psi
 50% Max Load: 22,833 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.0269 | -0.0091 | 1,371,951 |
| 2L | -0.0280 | -0.0107 | 1,408,717 |
| 3L | -0.0288 | -0.0093 | 1,248,504 |
| Average | | | 1,343,057 |

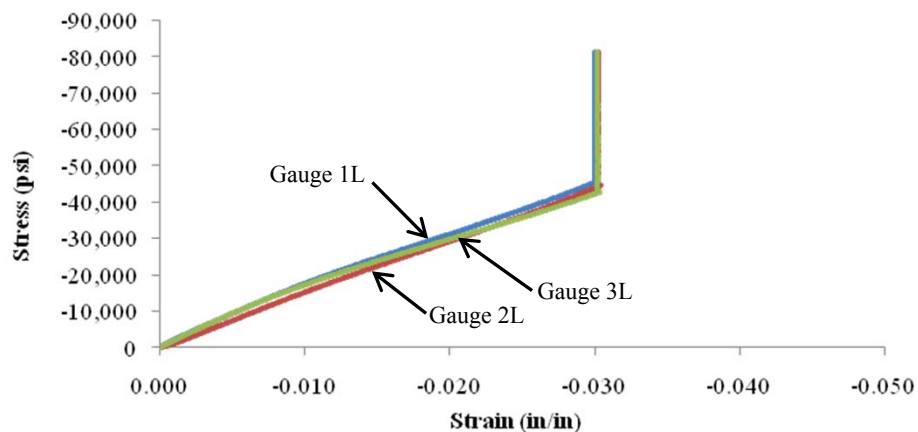
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 70F_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-CZ-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 39,694 lbs

Compressive Strength, SC_z : 71,303 psi

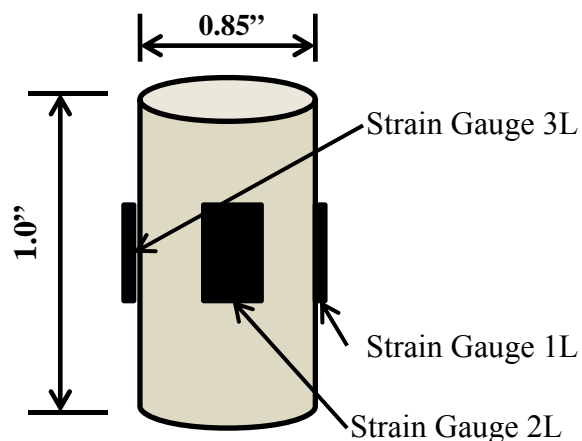
Compressive Modulus, E_z : 1,459,822 psi

Ultimate Strain, ϵ_z : 0.050 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT4-CZ-01-140-FY09 | 43,141 | 77,313 | 1,526,787 | 0.051 | Rupture |
| MAT4-CZ-02-140-FY09 | 38,322 | 68,555 | 1,498,791 | 0.047 | Rupture |
| MAT4-CZ-03-140-FY09 | 41,210 | 74,387 | 1,647,677 | 0.047 | Rupture |
| MAT4-CZ-04-140-FY09 | 36,991 | 65,704 | 1,211,900 | 0.055 | Rupture |
| MAT4-CZ-05-140-FY09 | 38,806 | 70,557 | 1,413,953 | 0.051 | Rupture |
| Average | 39,694 | 71,303 | 1,459,822 | 0.050 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for the Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-86 to G-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-01-140-FY09**
 Test Date: 6/13/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 43,141 lbs
 Maximum Stress, SC_z : 77,313 psi
 Elastic Modulus, E_z : 1,526,787 psi
 Ultimate Strain, ϵ_z : 0.051 in/in

Measured Specimen Dimensions:

Length, L: 1.01 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,628 psi
 50% Max Load: 21,570 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0230 | -0.0083 | 1,569,288 |
| 2L | -0.0236 | -0.0103 | 1,734,912 |
| 3L | -0.0273 | -0.0091 | 1,275,162 |
| Average | | | 1,526,787 |

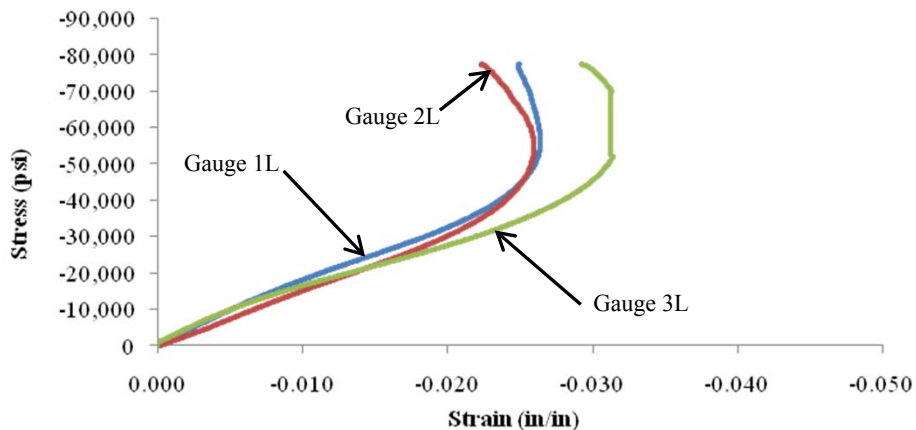
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-02-140-FY09**
 Test Date: 6/13/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 38,322 lbs
 Maximum Stress, SC_z : 68,555 psi
 Elastic Modulus, E_z : 1,498,791 psi
 Ultimate Strain, ϵ_z : 0.047 in/in

Measured Specimen Dimensions:

Length, L: 1.01 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,664 psi
 50% Max Load: 19,161 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0220 | -0.0073 | 1,401,684 |
| 2L | -0.0248 | -0.0089 | 1,297,557 |
| 3L | -0.0198 | -0.0084 | 1,797,132 |
| Average | | | 1,498,791 |

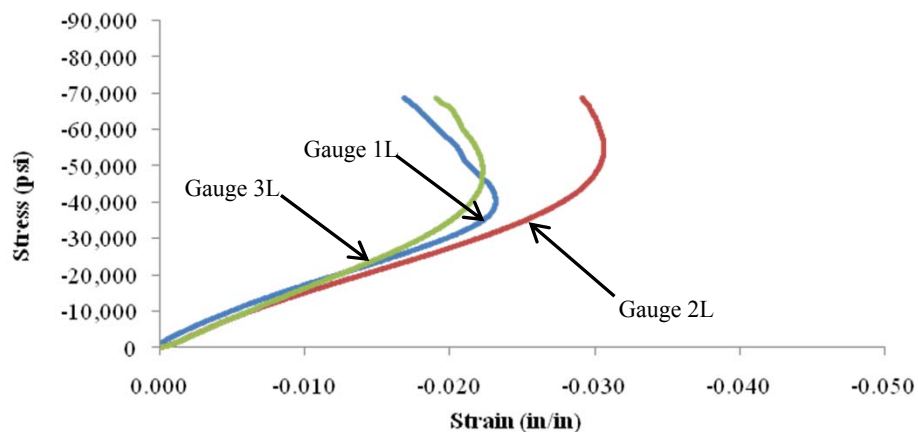
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-03-140 –FY09**
 Test Date: 6/13/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 42,210 lbs
 Maximum Stress, SC_z : 74,387 psi
 Elastic Modulus, E_z : 1,647,677 psi
 Ultimate Strain, ϵ_z : 0.047 in/in

Measured Specimen Dimensions:

Length, L: 1.00 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,242 psi
 50% Max Load: 20,605 psi

PICTURE OF SPECIMEN PRE-TEST



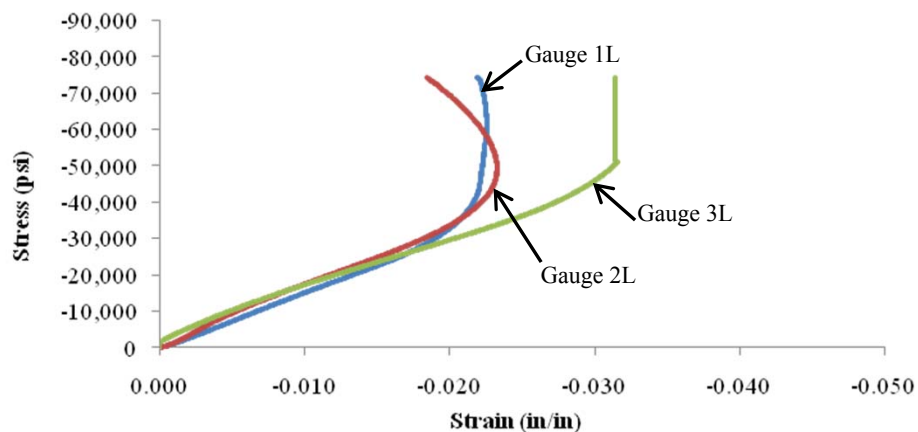
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0211 | -0.0098 | 1,968,127 |
| 2L | -0.0214 | -0.0082 | 1,700,440 |
| 3L | -0.0256 | -0.0081 | 1,274,463 |
| Average | | | 1,647,677 |

Stress-Strain Curve 140_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-04-140-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 36,991 lbs
 Maximum Stress, SC_z : 65,704 psi
 Elastic Modulus, E_z : 1,211,900 psi
 Ultimate Strain, ϵ_z : 0.055 in/in

Measured Specimen Dimensions:

Length, L: 1.01 in
 Diameter, D: 0.85 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,398 psi
 50% Max Load: 18,496 psi

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0273 | -0.0119 | 1,286,966 |
| 2L | -0.0249 | -0.0064 | 1,066,706 |
| 3L | -0.0237 | -0.0084 | 1,282,030 |
| Average | | | 1,211,900 |

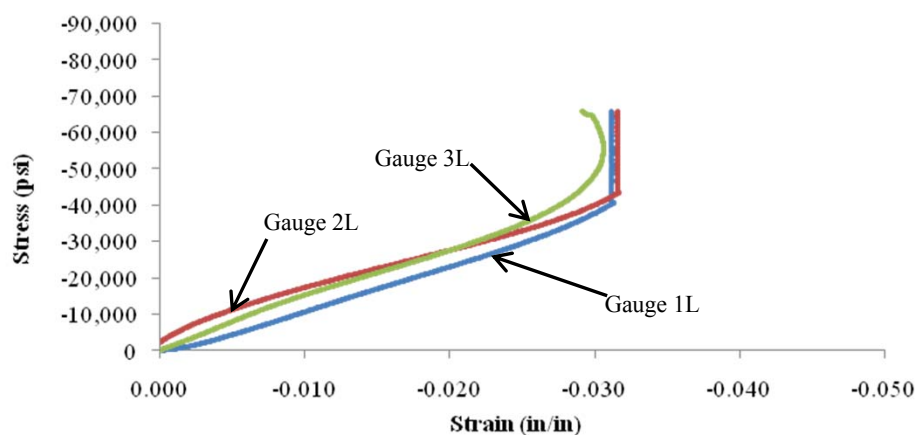
PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve 140F_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-CZ-05-140-FY09**
 Test Date: 6/14/2011
 Specimen Received: 6/8/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 38,806 lbs
 Maximum Stress, SC_z : 70,557 psi
 Elastic Modulus, E_z : 1,413,953 psi
 Ultimate Strain, ϵ_z : 0.051 in/in

Measured Specimen Dimensions:

Length, L: 1.00 in
 Diameter, D: 0.84 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 7,761 psi
 50% Max Load: 19,403 psi

PICTURE OF SPECIMEN PRE-TEST



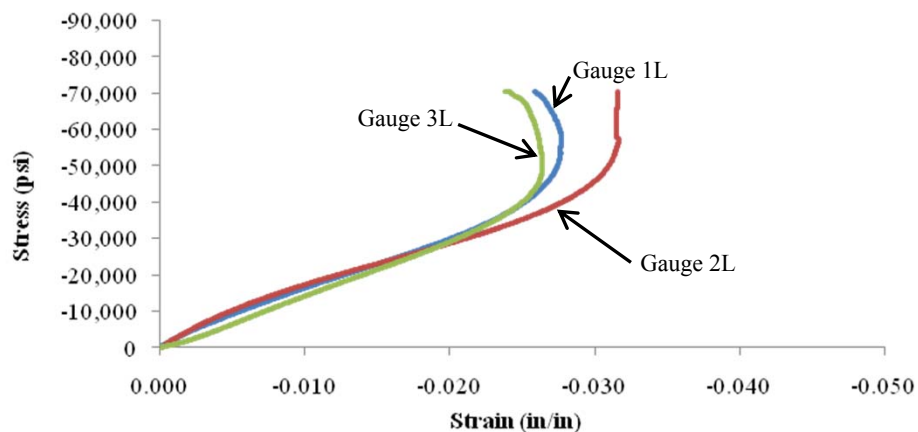
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Elastic Modulus E_z , (psi) |
| 1L | -0.0231 | -0.0083 | 1,433,885 |
| 2L | -0.0250 | -0.0076 | 1,213,310 |
| 3L | -0.0232 | -0.0100 | 1,594,664 |
| Average | | | 1,413,953 |

Stress-Strain Curve 140F_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXZ-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 467 lbs

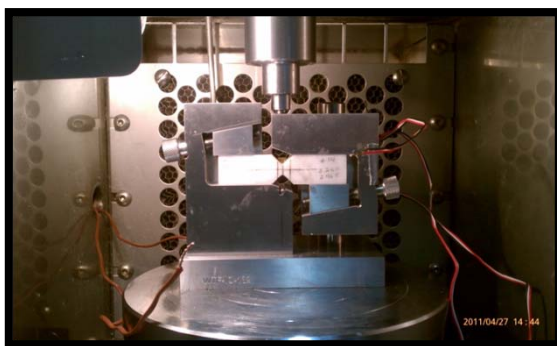
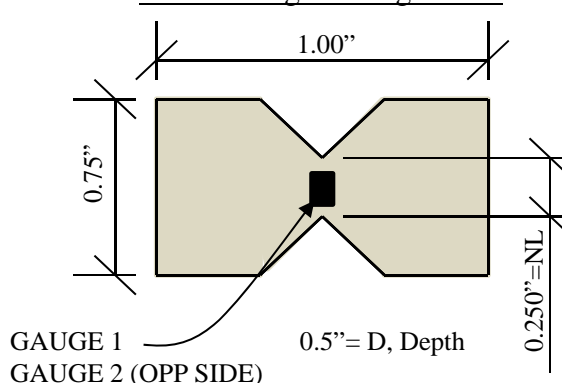
Shear Strength, S_{xz} : 3,889 psi

Shear Modulus, G_{xz} : 1,162,624 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT4-SXZ-01-N40-FY09 | 506 | 3,930 | 1,149,368 | Shear |
| 2 | MAT4-SXZ-02-N40-FY09 | 537 | 4,078 | 1,268,149 | Shear |
| 3 | MAT4-SXZ-03-N40-FY09 | 503 | 3,995 | 996,379 | Shear |
| 4 | MAT4-SXZ-04-N40-FY09 | 391 | 3,905 | 1,267,642 | Shear |
| 5 | MAT4-SXZ-05-N40-FY09 | 399 | 3,537 | 1,131,584 | Shear |
| Average | | 467 | 3,889 | 1,162,624 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets G-92 to G-96
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-01-N40-FY09
 Test Date: 5/27/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

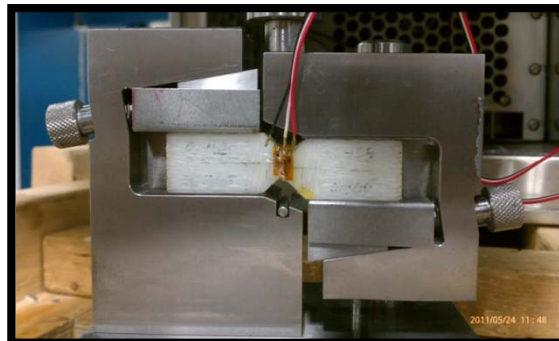
Average Material Properties:

Ultimate Load, P_{max} : 506 lbs
 Shear Stress, S_{xz} : 3,930 psi
 Shear Modulus, G_{xz} : 1,149,368 psi

Measured Specimen Dimensions:

Depth, D: 0.444 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 253 lbs
 20% Max Load: 101 lbs

PICTURE OF SPECIMEN PRE-TEST



Pic. above: Not specimen for this worksheet

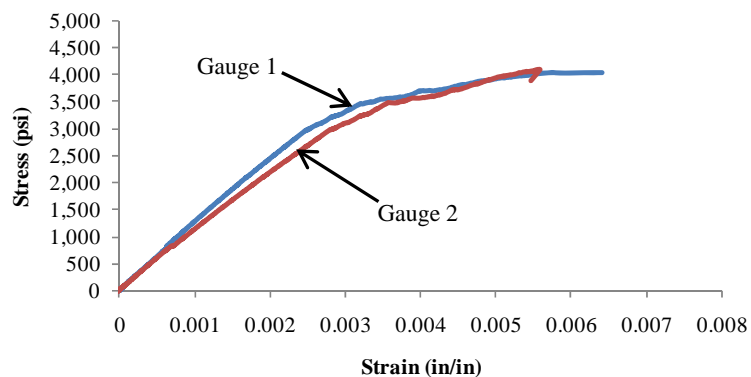
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0016 | 0.0006 | 1,247,957 |
| 2 | 0.0018 | 0.0007 | 1,050,779 |
| Average | | | 1,149,368 |

Stress-Strain Curve N40_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-02-N40-FY09
 Test Date: 5/31/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 537 lbs
 Shear Stress, S_{xz} : 4,078 psi
 Shear Modulus, G_{xz} : 1,268,149 psi

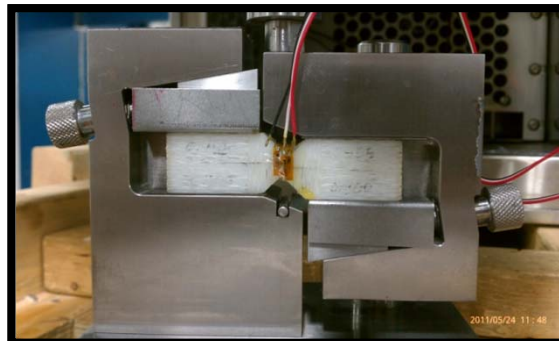
Measured Specimen Dimensions:

Depth, D: 0.454 in
 Notch Length, NL: 0.290 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 268 lbs
 20% Max Load: 107 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0018 | 0.0006 | 1,072,340 |
| 2 | 0.0014 | 0.0006 | 1,463,958 |
| Average | | | 1,268,149 |

PICTURE OF SPECIMEN PRE-TEST

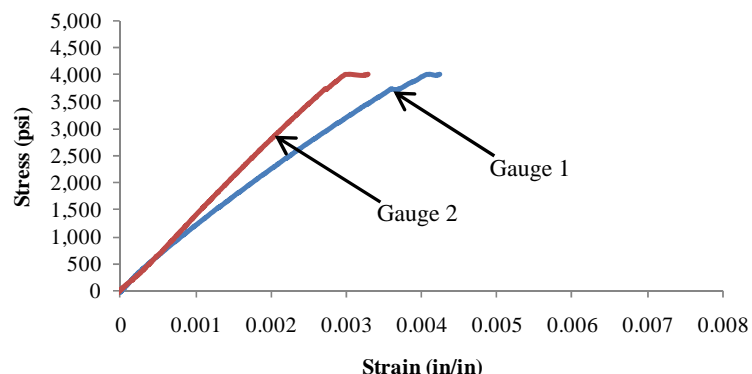


Pic. above: Not specimen for this worksheet

PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-03-N40-FY09
 Test Date: 5/31/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 503 lbs
 Shear Stress, S_{xz} : 3,995 psi
 Shear Modulus, G_{xz} : 996,379 psi

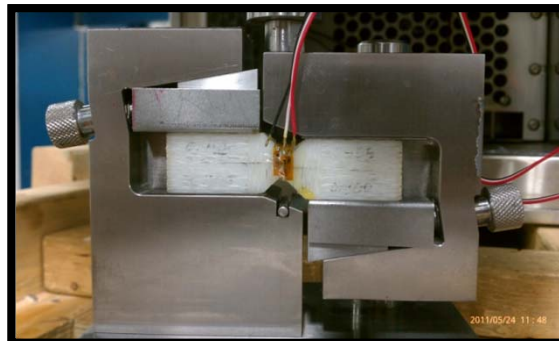
Measured Specimen Dimensions:

Depth, D: 0.450 in
 Notch Length, NL: 0.280 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 252 lbs
 20% Max Load: 101 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0021 | 0.0008 | 910,227 |
| 2 | 0.0018 | 0.0007 | 1,082,532 |
| Average | | | 996,379 |

PICTURE OF SPECIMEN PRE-TEST

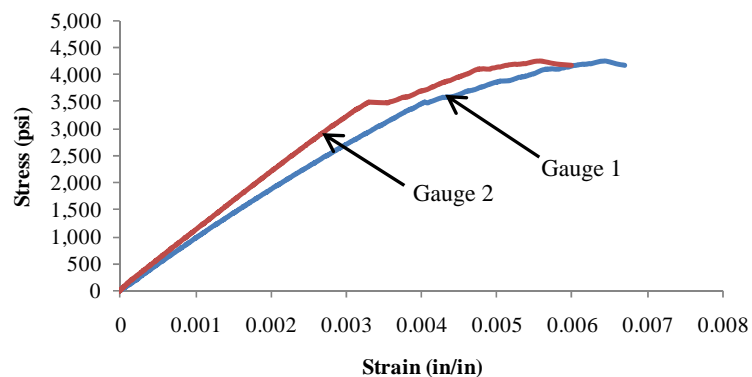


Pic. above: Not specimen for this worksheet

PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-04-N40-FY09
 Test Date: 6/1/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 391 lbs
 Shear Stress, S_{xz} : 3,905 psi
 Shear Modulus, G_{xz} : 1,267,642 psi

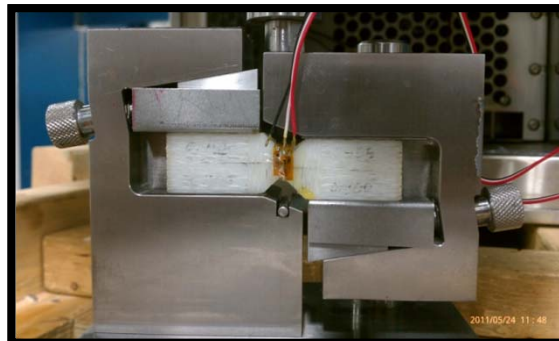
Measured Specimen Dimensions:

Depth, D: 0.466 in
 Notch Length, NL: 0.215 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 196 lbs
 20% Max Load: 78 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

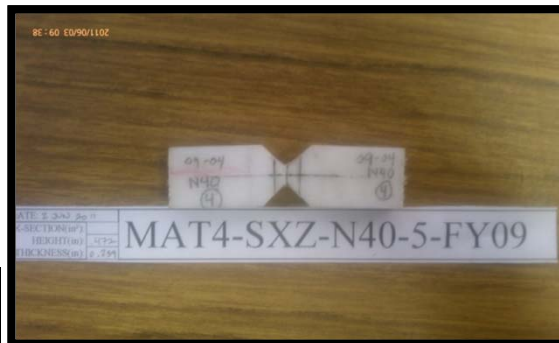
| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0016 | 0.0006 | 1,144,751 |
| 2 | 0.0014 | 0.0006 | 1,390,534 |
| Average | | | 1,267,642 |

PICTURE OF A SPECIMEN PRE-TEST

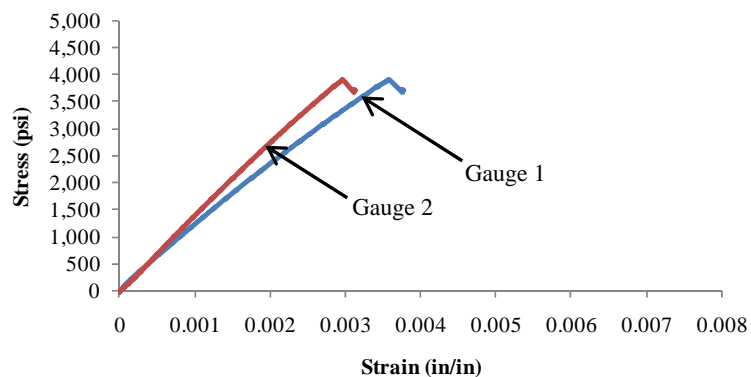


Pic. above: Not specimen for this worksheet

PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-04-N40-FY09
 Test Date: 6/1/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 399 lbs
 Shear Stress, S_{xz} : 3,537 psi
 Shear Modulus, G_{xz} : 1,131,584 psi

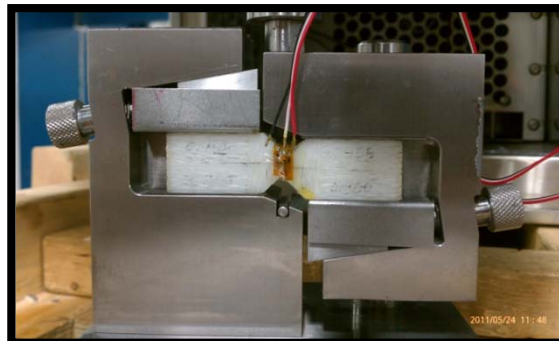
Measured Specimen Dimensions:

Depth, D: 0.472 in
 Notch Length, NL: 0.239 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 200 lbs
 20% Max Load: 80 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

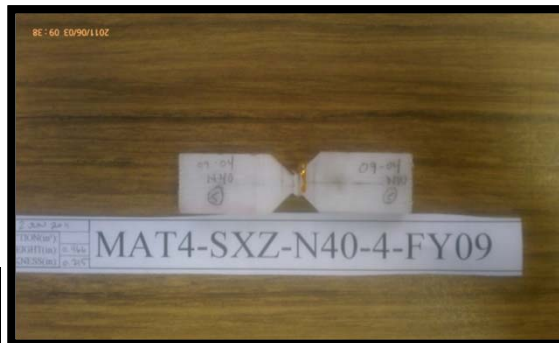
| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0016 | 0.0006 | 1,040,161 |
| 2 | 0.0015 | 0.0006 | 1,223,007 |
| Average | | | 1,131,584 |

PICTURE OF A SPECIMEN PRE-TEST

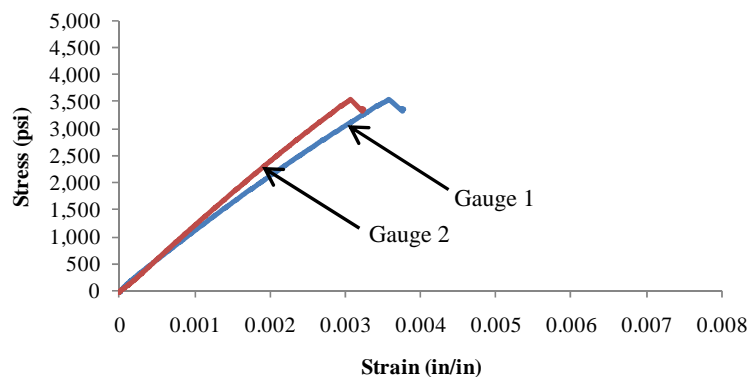


Pic. above: Not specimen for this worksheet

PICTURE OF SPECIMEN POST-TEST



Stress-Strain Curve N40_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXZ-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 469 lbs

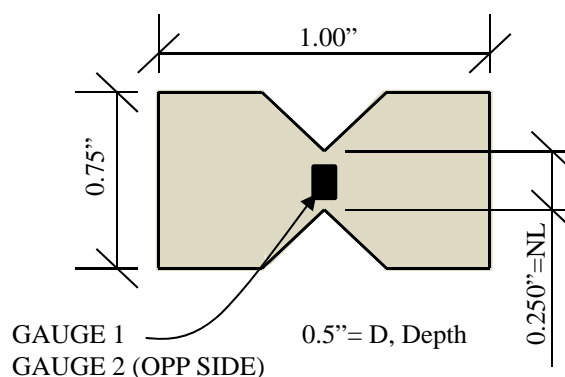
Shear Strength, S_{xz} : 3,913 psi

Shear Modulus, G_{xz} : 1,045,073 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|---------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT4-SXZ-01-70-FY09 | 568 | 4,162 | 903,887 | Shear |
| 2 | MAT4-SXZ-02-70-FY09 | 538 | 3,989 | 987,195 | Shear |
| 4 | MAT4-SXZ-04-70-FY09 | 385 | 3,598 | 1,186,842 | Shear |
| 5 | MAT4-SXZ-05-70-FY09 | 510 | 4,137 | 985,682 | Shear |
| 7 | MAT4-SXZ-07-70-FY09 | 346 | 3,679 | 1,161,757 | Shear |
| Average | | 469 | 3,913 | 1,045,073 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets G-98 to G-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-01-70-FY09
 Test Date: 5/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

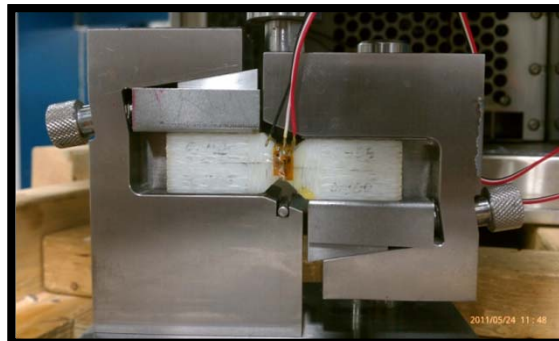
Average Material Properties:

Ultimate Load, P_{max} : 568 lbs
 Shear Stress, S_{xz} : 4,162 psi
 Shear Modulus, G_{xz} : 903,887 psi

Measured Specimen Dimensions:

Depth, D: 0.455 in
 Notch Length, NL: 0.300 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 284 lbs
 20% Max Load: 114 lbs

PICTURE OF SPECIMEN PRE-TEST



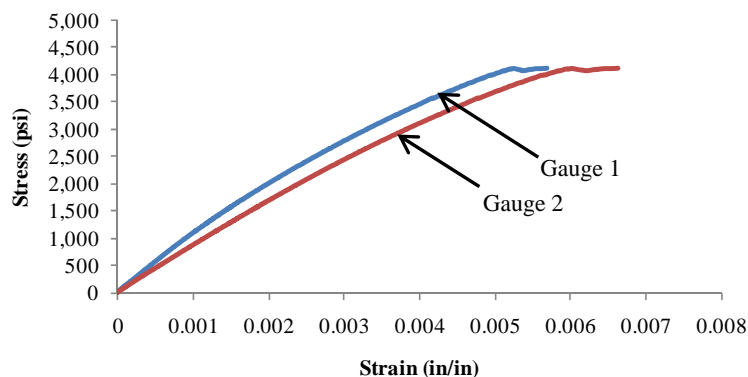
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0025 | 0.0009 | 803,868 |
| 2 | 0.0021 | 0.0008 | 1,003,905 |
| Average | | | 903,887 |

Stress-Strain Curve 70F_01_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-02-70-FY09
 Test Date: 5/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

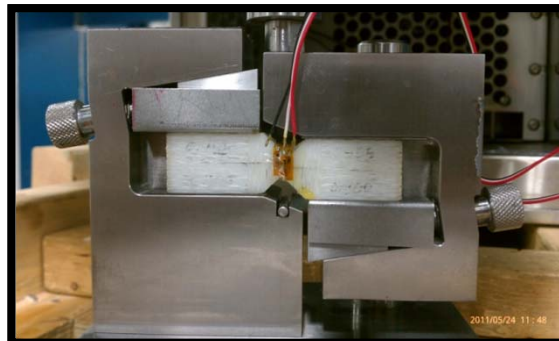
Average Material Properties:

Ultimate Load, P_{max} : 538 lbs
 Shear Stress, S_{xz} : 3,989 psi
 Shear Modulus, G_{xz} : 987,195 psi

Measured Specimen Dimensions:

Depth, D: 0.450 in
 Notch Length, NL: 0.300 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 269 lbs
 20% Max Load: 108 lbs

PICTURE OF SPECIMEN PRE-TEST



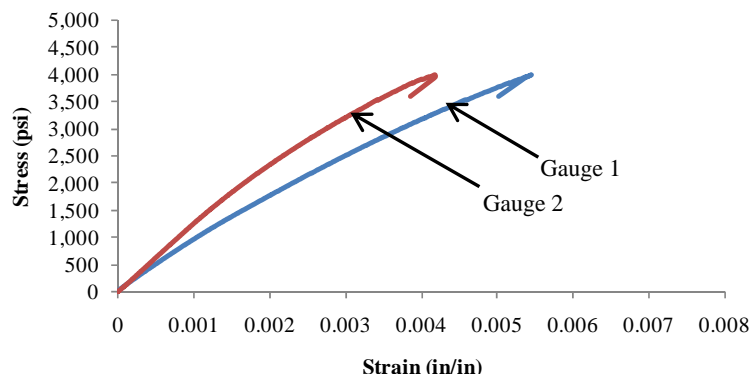
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0023 | 0.0008 | 805,506 |
| 2 | 0.0017 | 0.0006 | 1,168,884 |
| Average | | | 987,195 |

Stress-Strain Curve 70F_02_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-04-70-FY09
 Test Date: 5/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

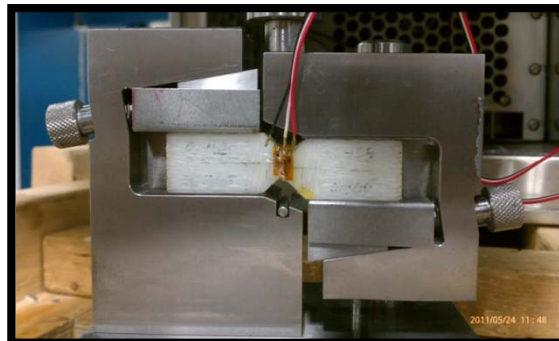
Average Material Properties:

Ultimate Load, P_{max} : 385 lbs
 Shear Stress, S_{xz} : 3,598 psi
 Shear Modulus, G_{xz} : 1,186,842 psi

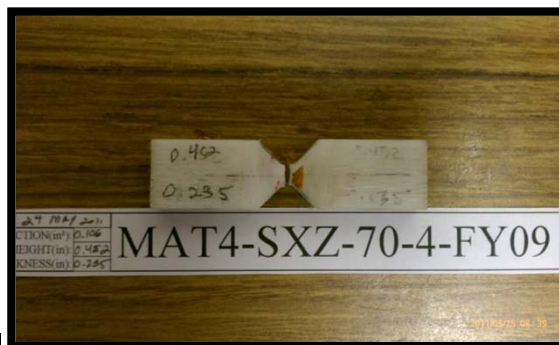
Measured Specimen Dimensions:

Depth, D: 0.455 in
 Notch Length, NL: 0.235 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 192 lbs
 20% Max Load: 77 lbs

PICTURE OF SPECIMEN PRE-TEST



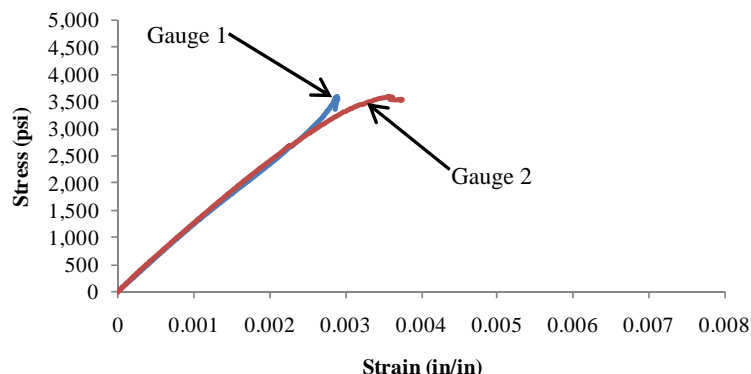
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0015 | 0.00057 | 1,170,448 |
| 2 | 0.0014 | 0.00055 | 1,203,237 |
| Average | | | 1,186,842 |

Stress-Strain Curve 70F_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-05-70-FY09
 Test Date: 5/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

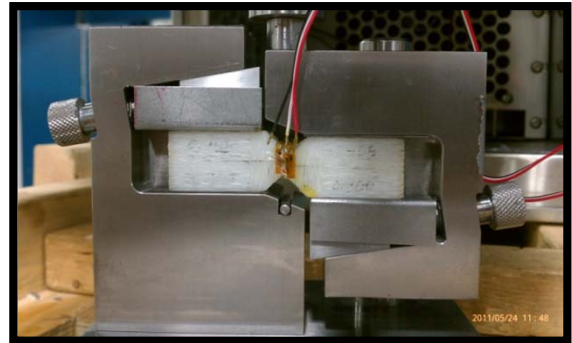
Average Material Properties:

Ultimate Load, P_{max} : 510 lbs
 Shear Stress, S_{xz} : 4,137 psi
 Shear Modulus, G_{xz} : 985,682 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.246 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 255 lbs
 20% Max Load: 102 lbs

PICTURE OF SPECIMEN PRE-TEST



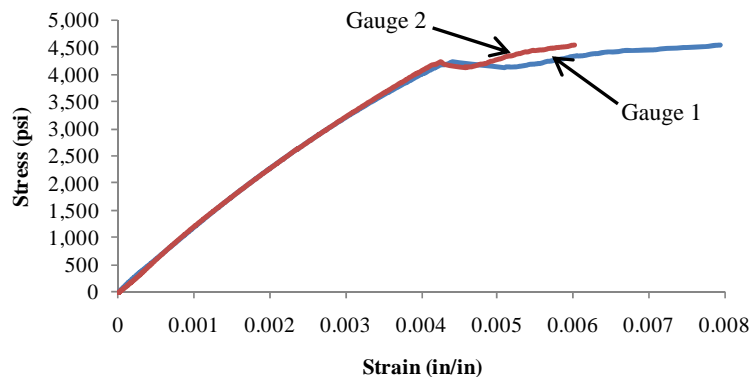
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0007 | 989,019 |
| 2 | 0.0020 | 0.0007 | 982,344 |
| Average | | | 985,682 |

Stress-Strain Curve 70F_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-07-70-FY09
 Test Date: 5/26/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

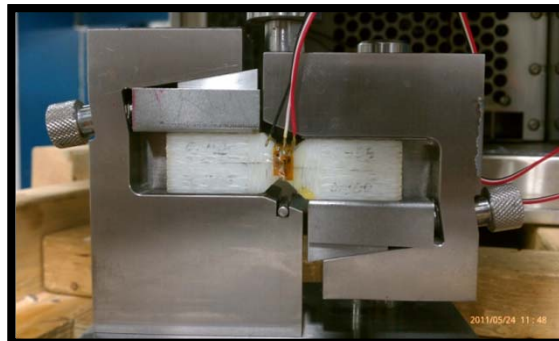
Average Material Properties:

Ultimate Load, P_{max} : 346 lbs
 Shear Stress, S_{xz} : 3,679 psi
 Shear Modulus, G_{xz} : 1,161,757 psi

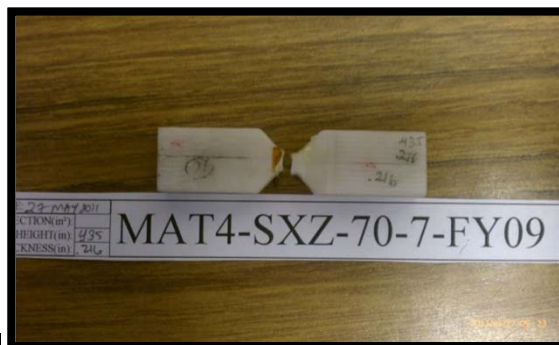
Measured Specimen Dimensions:

Depth, D: 0.435 in
 Notch Length, NL: 0.216 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 173 lbs
 20% Max Load: 69 lbs

PICTURE OF SPECIMEN PRE-TEST



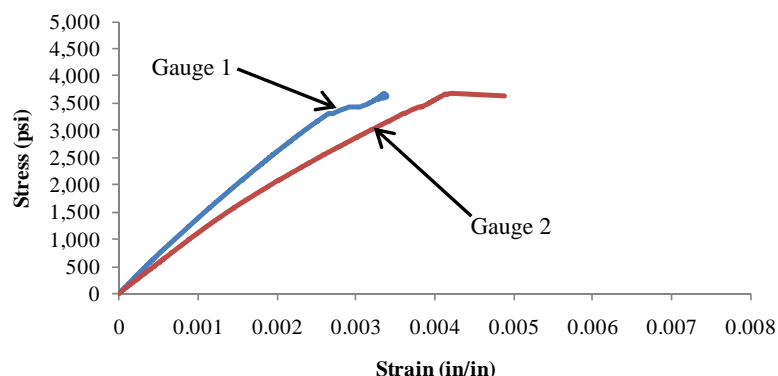
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0014 | 0.0005 | 1,305,254 |
| 2 | 0.0017 | 0.0006 | 1,018,260 |
| Average | | | 1,161,757 |

Stress-Strain Curve 70F_07_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- * Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-SXZ-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xz} , S_{xz}

Ultimate Load, P_{max} : 309 lbs

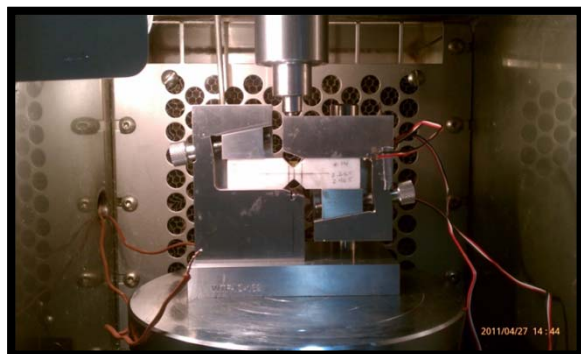
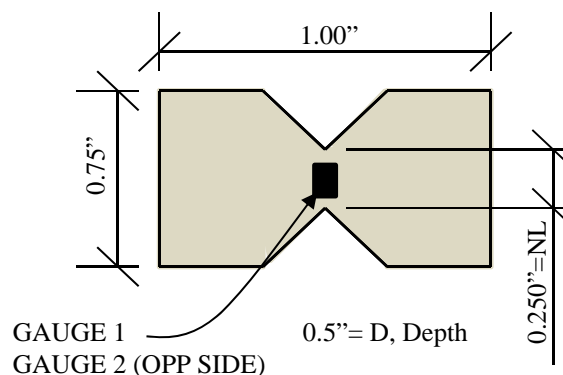
Shear Strength, S_{xz} : 3,015 psi

Shear Modulus, G_{xz} : 779,597 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 3 | MAT4-SXZ-03-140-FY09 | 288 | 2,770 | 810,335 | Shear |
| 4 | MAT4-SXZ-04-140-FY09 | 310 | 2,975 | 694,130 | Shear |
| 5 | MAT4-SXZ-05-140-FY09 | 316 | 3,054 | 739,328 | Shear |
| 10 | MAT4-SXZ-10-140-FY09 | 297 | 2,923 | 814,347 | Shear |
| 11 | MAT4-SXZ-11-140-FY09 | 334 | 3,351 | 839,846 | Shear |
| Average | | 309 | 3,015 | 779,597 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140° F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS****Notes:**

- 1) Individual specimen results are shown on Sheets G-104 to G-108
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-03-140-FY09
 Test Date: 5/27/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

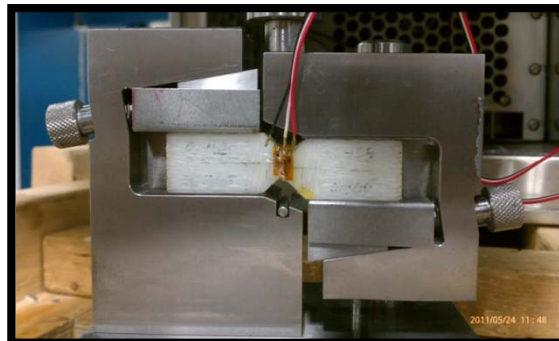
Average Material Properties:

Ultimate Load, P_{max} : 288 lbs
 Shear Stress, S_{xz} : 2,770 psi
 Shear Modulus, G_{xz} : 810,335 psi

Measured Specimen Dimensions:

Depth, D: 0.469 in
 Notch Length, NL: 0.222 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 144 lbs
 20% Max Load: 58 lbs

PICTURE OF SPECIMEN PRE-TEST



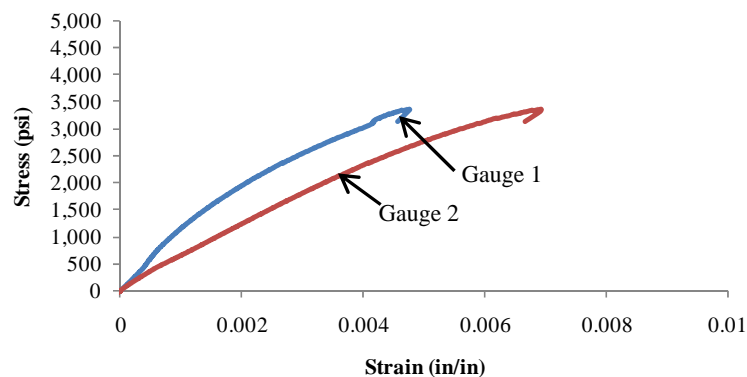
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0013 | 0.0005 | 1,045,594 |
| 2 | 0.0022 | 0.0008 | 575,077 |
| Average | | | 810,335 |

Stress-Strain Curve 140_03_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-04-140-FY09
 Test Date: 5/27/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

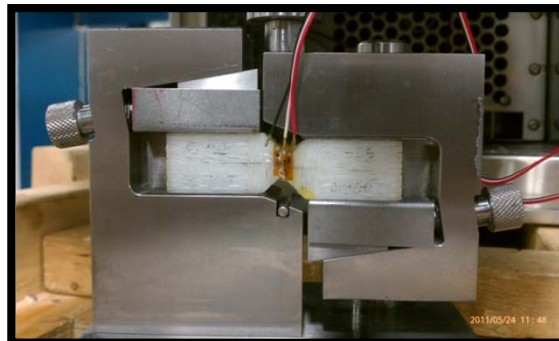
Average Material Properties:

Ultimate Load, P_{max} : 310 lbs
 Shear Stress, S_{xz} : 2,975 psi
 Shear Modulus, G_{xz} : 694,130 psi

Measured Specimen Dimensions:

Depth, D: 0.469 in
 Notch Length, NL: 0.222 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 155 lbs
 20% Max Load: 62 lbs

PICTURE OF SPECIMEN PRE-TEST



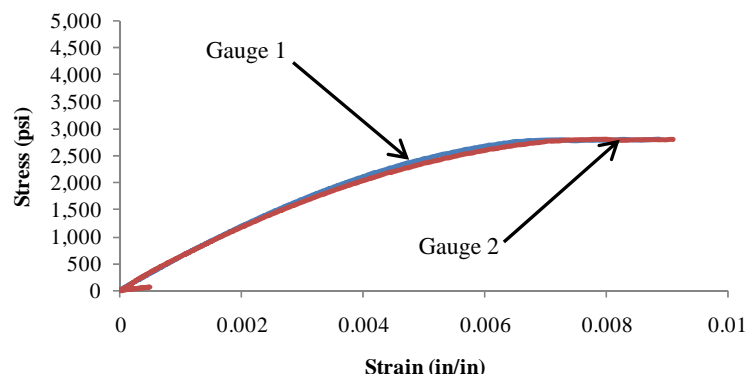
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0020 | 0.0008 | 711,928 |
| 2 | 0.0020 | 0.0007 | 676,332 |
| Average | | | 694,130 |

Stress-Strain Curve 140_04_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-05-140-FY09
 Test Date: 6/2/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

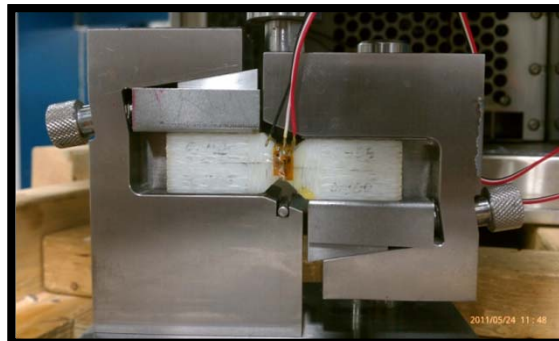
Average Material Properties:

Ultimate Load, P_{max} : 316 lbs
 Shear Stress, S_{xz} : 3,054 psi
 Shear Modulus, G_{xz} : 739,328 psi

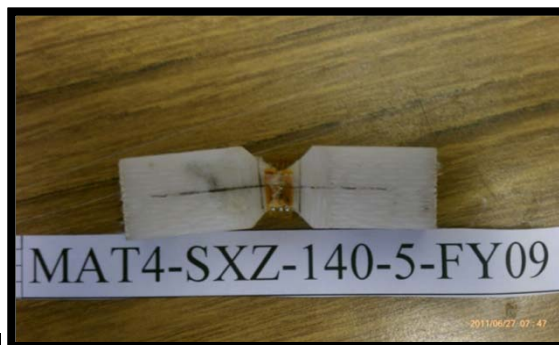
Measured Specimen Dimensions:

Depth, D: 0.470 in
 Notch Length, NL: 0.220 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 158 lbs
 20% Max Load: 63 lbs

PICTURE OF SPECIMEN PRE-TEST



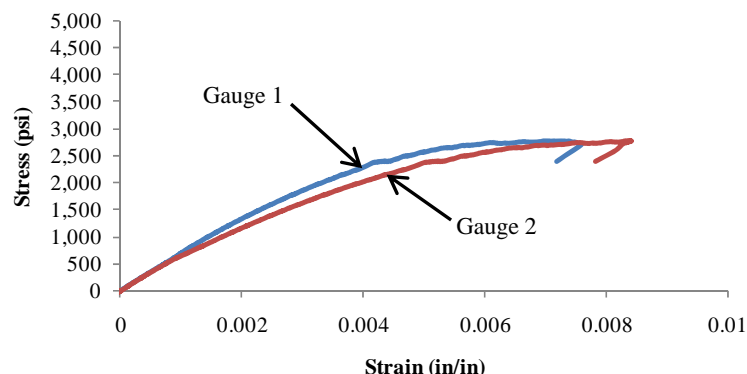
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0018 | 0.0007 | 661,921 |
| 2 | 0.0021 | 0.0007 | 525,506 |
| Average | | | 593,713 |

Stress-Strain Curve 140_05_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-10-140-FY09
 Test Date: 6/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

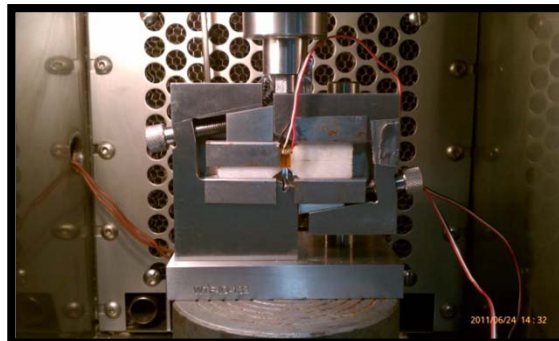
Average Material Properties:

Ultimate Load, P_{max} : 297 lbs
 Shear Stress, S_{xz} : 2,923 psi
 Shear Modulus, G_{xz} : 814,347 psi

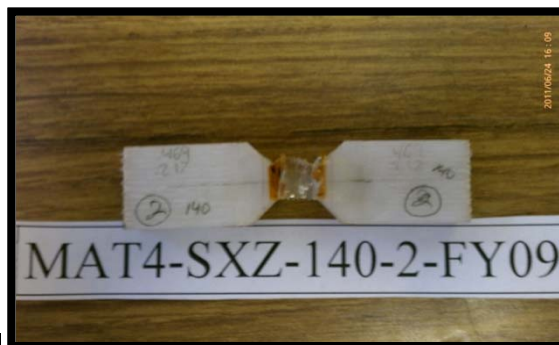
Measured Specimen Dimensions:

Depth, D: 0.469 in
 Notch Length, NL: 0.217 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 149 lbs
 20% Max Load: 59 lbs

PICTURE OF SPECIMEN PRE-TEST



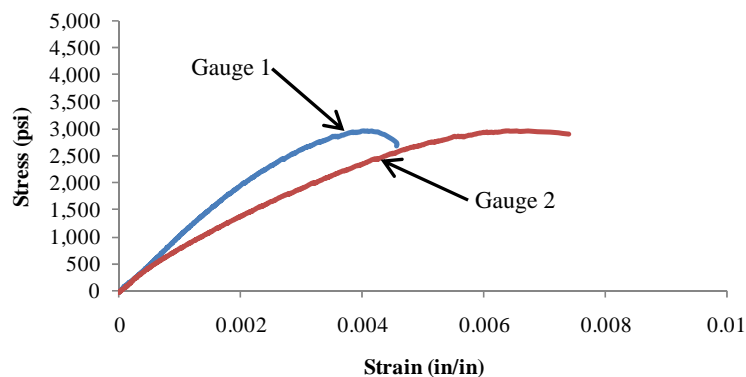
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0014 | 0.0006 | 1,024,113 |
| 2 | 0.0021 | 0.0007 | 604,582 |
| Average | | | 814,347 |

Stress-Strain Curve 140_10_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT4-SXZ-11-140-FY09
 Test Date: 6/24/11
 Specimen Received: 5/11/11
 Properties Measured: S_{xz} , G_{xz}

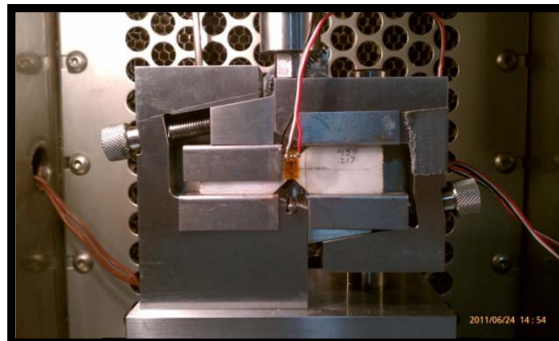
Average Material Properties:

Ultimate Load, P_{max} : 334 lbs
 Shear Stress, S_{xz} : 3,351 psi
 Shear Modulus, G_{xz} : 839,846 psi

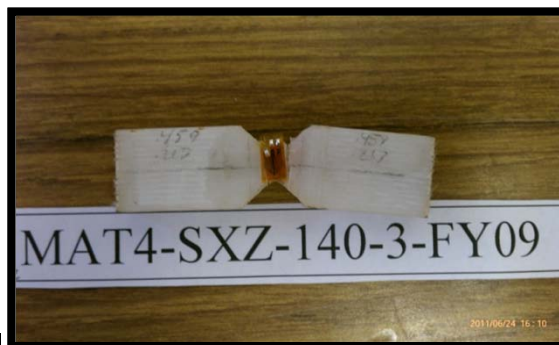
Measured Specimen Dimensions:

Depth, D: 0.459 in
 Notch Length, NL: 0.217 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 167 lbs
 20% Max Load: 67 lbs

PICTURE OF SPECIMEN PRE-TEST



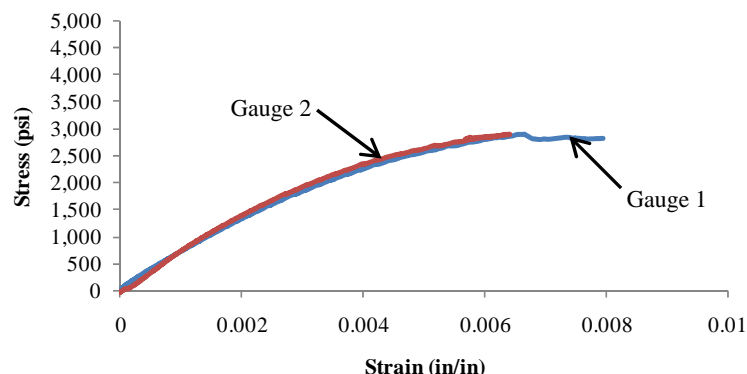
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Modulus (G_{xz}) (psi) |
| 1 | 0.0019 | 0.0006 | 786,846 |
| 2 | 0.0018 | 0.0007 | 892,846 |
| Average | | | 839,846 |

Stress-Strain Curve 140_11_(09-04)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-OP-N40-FY09
 Material: Huntsman Epoxy SC-15, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1538
 Maximum Load, P_z : 3,204 lbs

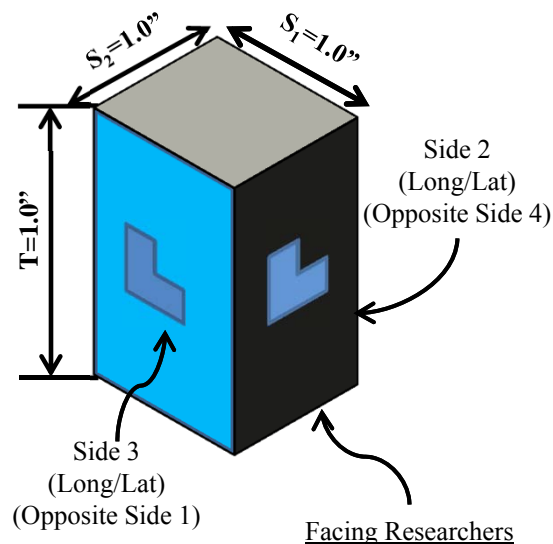
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT4-OP-N40-1-FY09 | 3,372 | 0.1514 | Rupture |
| 2 | MAT4-OP-N40-2-FY09 | 3,230 | 0.2193 | Rupture |
| 3 | MAT4-OP-N40-3-FY09 | 2,605 | 0.1528 | Rupture |
| 4 | MAT4-OP-N40-4-FY09 | 3,582 | 0.1148 | Rupture |
| 5 | MAT4-OP-N40-5-FY08 | 3,230 | 0.1309 | Bondline |
| Average | | 3,204 | 0.1538 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) Reference G-110 thru G-114 for individual specimen data.
- 2) 6 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-N40-1-FY09**
 Test Date: 4/19/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,372 lbs
 Poisson's Ratio, v_{xz} : 0.1514

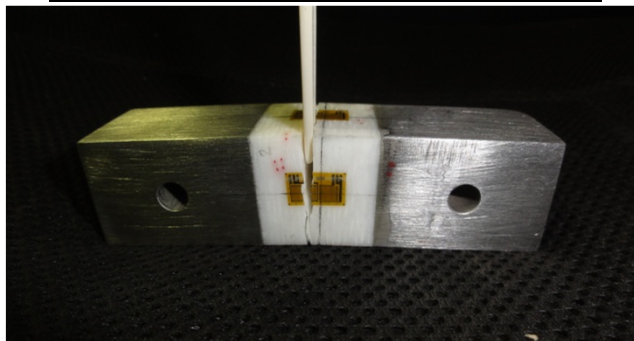
Measured Specimen Dimensions:

Thickness: 0.910 in
 Side 1: 0.998 in
 Side 2: 0.998 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,686 lbs
 20% Max Load: 674 lbs

PICTURE OF SPECIMEN PRE-TEST

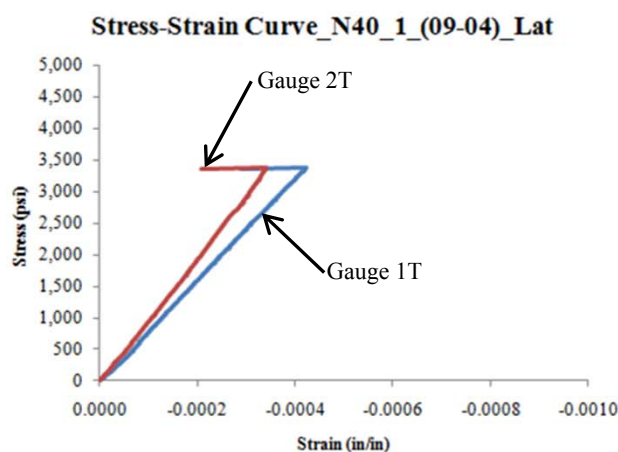
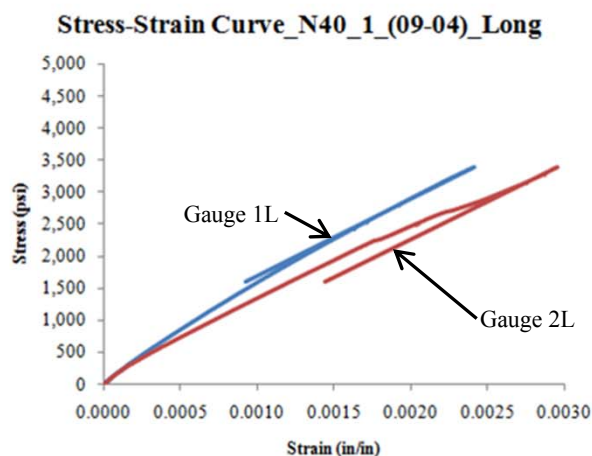


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001073 | 0.000385 | 1T | -0.000213 | -0.000089 | 0.1789 |
| 2L | 0.001291 | 0.000453 | 2T | -0.000178 | -0.000075 | 0.1238 |
| Average | | | | | | 0.1514 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-N40-2-FY09**
 Test Date: 4/20/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,230 lbs
 Poisson's Ratio, v_{xz} : 0.2193

Measured Specimen Dimensions:

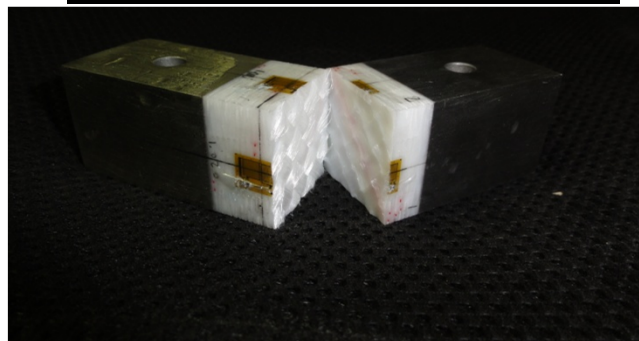
Thickness: 0.902 in
 Side 1: 0.995 in
 Side 2: 0.996 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,615 lbs
 20% Max Load: 646 lbs

PICTURE OF SPECIMEN PRE-TEST

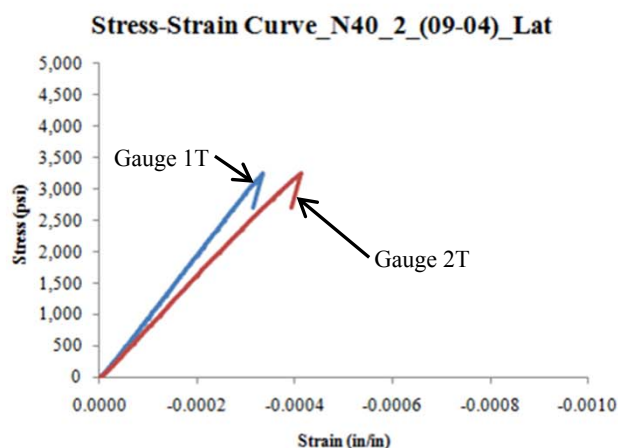
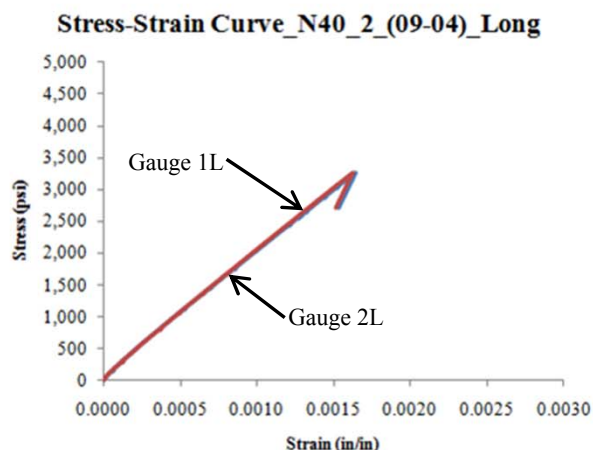


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000781 | 0.000287 | 1T | -0.000168 | -0.000070 | 0.1979 |
| 2L | 0.000778 | 0.000289 | 2T | -0.000200 | -0.000082 | 0.2407 |
| Average | | | | | | 0.2193 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-N40-3-FY09**
 Test Date: 4/22/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

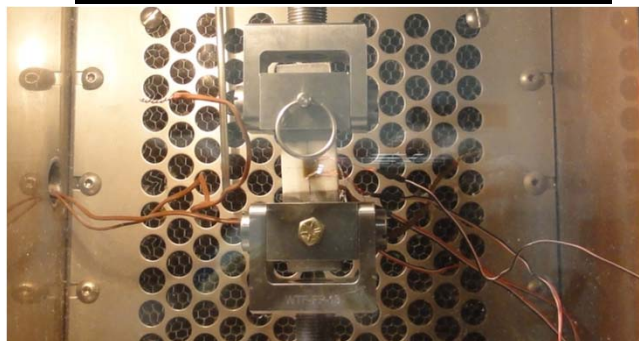
Average Material Properties:

Maximum Load, P_z : 2,605 lbs
 Poisson's Ratio, v_{xz} : 0.1528

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.992 in
 Side 2: 0.996 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,302 lbs
 20% Max Load: 521 lbs

PICTURE OF SPECIMEN PRE-TEST

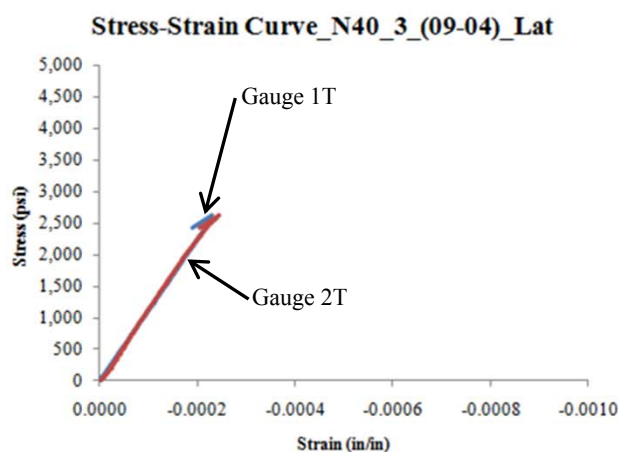
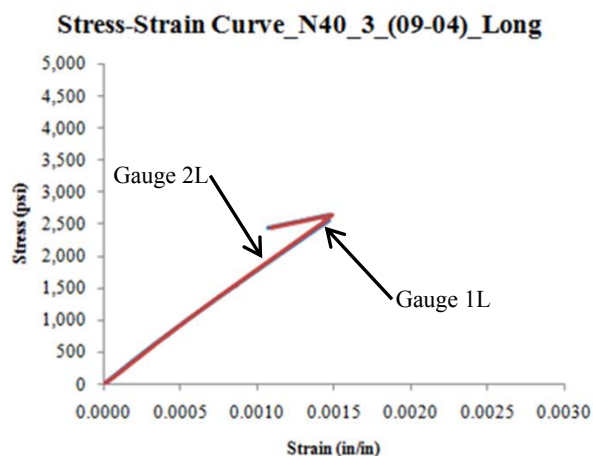


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000725 | 0.000274 | 1T | -0.000119 | -0.000050 | 0.1539 |
| 2L | 0.000725 | 0.000284 | 2T | -0.000115 | -0.000048 | 0.1516 |
| Average | | | | | | 0.1528 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-N40-4-FY09**
 Test Date: 4/22/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

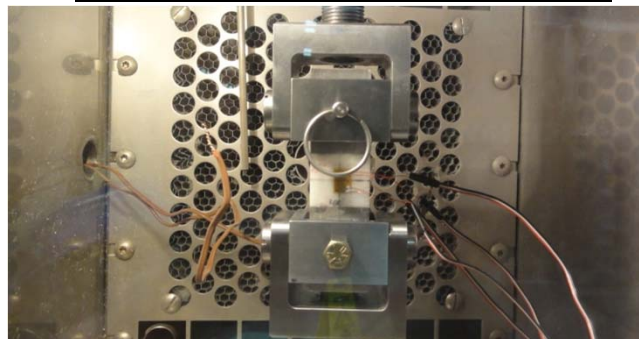
Average Material Properties:

Maximum Load, P_z : 3,582 lbs
 Poisson's Ratio, v_{xz} : 0.1148

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.994 in
 Side 2: 0.997 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,791 lbs
 20% Max Load: 716 lbs

PICTURE OF SPECIMEN PRE-TEST

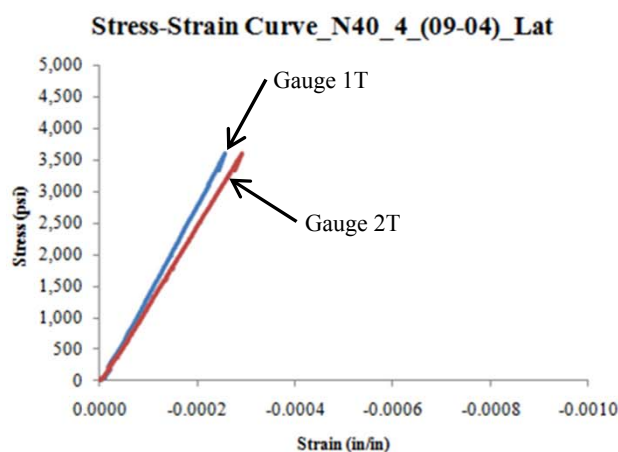
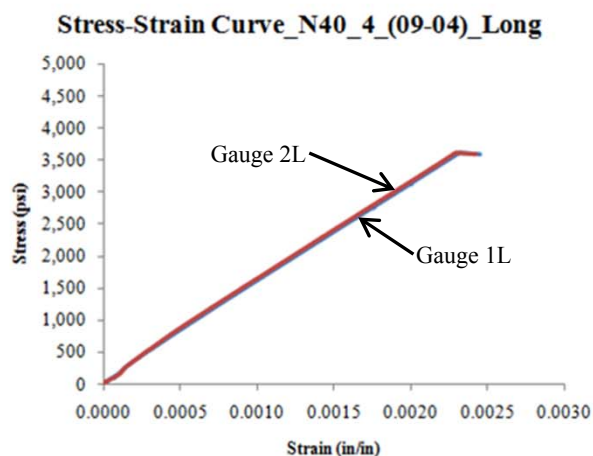


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.001122 | 0.000420 | 1T | -0.000132 | -0.000057 | 0.1066 |
| 2L | 0.001102 | 0.000406 | 2T | -0.000150 | -0.000064 | 0.1229 |
| Average | | | | | | 0.1148 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-N40-5-FY09**
 Test Date: 4/22/2011
 Specimen Received: 2/25/2011
 Properties Measured: v_{xz}

Average Material Properties:

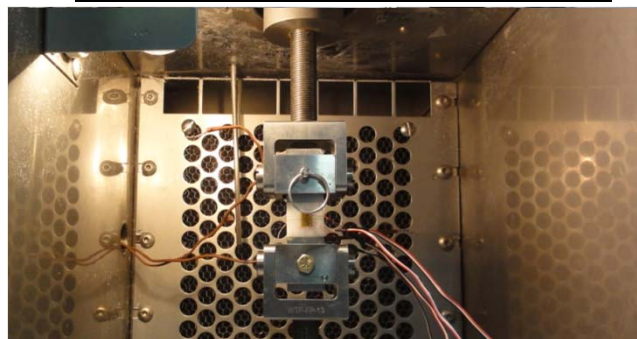
Maximum Load, P_z : 3,230 lbs
 Poisson's Ratio, v_{xz} : 0.1309

Measured Specimen Dimensions:

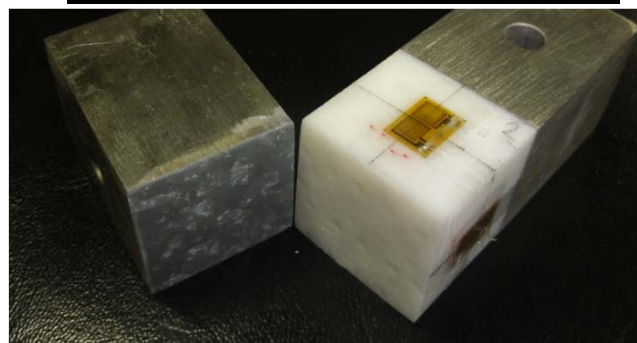
Thickness: 0.902 in
 Side 1: 0.995 in
 Side 2: 0.996 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,615 lbs
 20% Max Load: 646 lbs

PICTURE OF SPECIMEN PRE-TEST

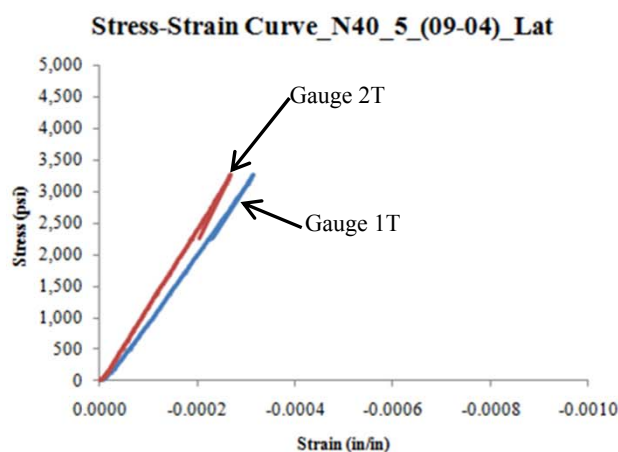
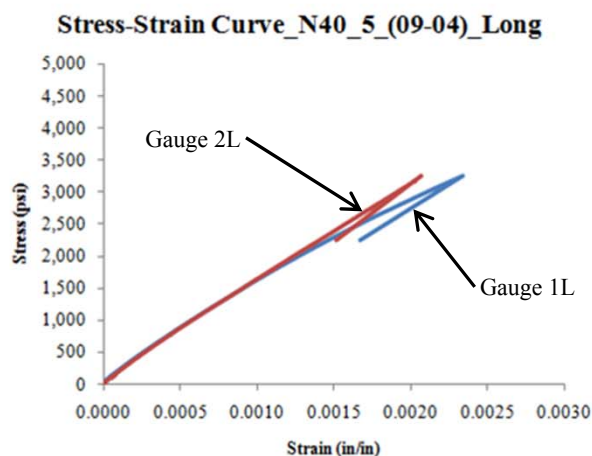


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000994 | 0.000346 | 1T | -0.000167 | -0.000077 | 0.1387 |
| 2L | 0.000983 | 0.000354 | 2T | -0.000138 | -0.000061 | 0.1231 |
| Average | | | | | | 0.1309 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

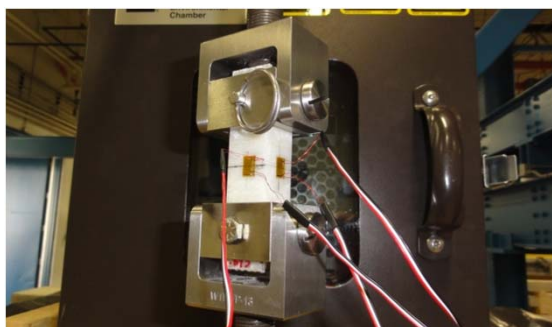
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT4-OP-70-FY09**
 Material: **Huntsman Epoxy Resin SC-15, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.1404**
 Maximum Load, P_z : **1,013 lbs**

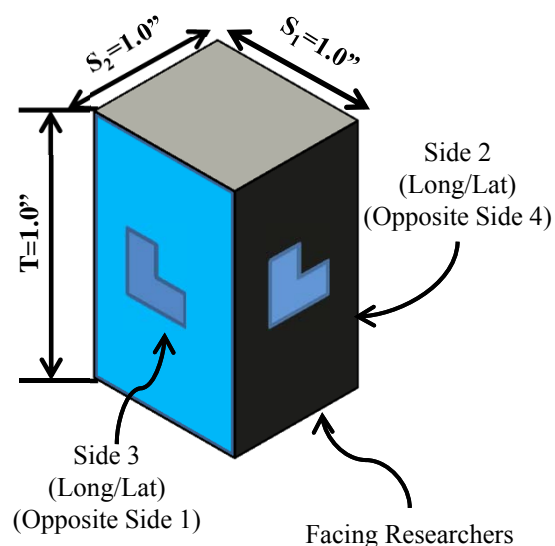
| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|-------------------|----------------------|-----------------------------|--------------|
| 1 | MAT4-OP-70-1-FY09 | 887 | 0.1242 | Rupture |
| 2 | MAT4-OP-70-2-FY09 | 1,162 | 0.1257 | Rupture |
| 3 | MAT4-OP-70-3-FY09 | 1,048 | 0.1556 | Rupture |
| 4 | MAT4-OP-70-4-FY09 | 954 | 0.1560 | Rupture |
| 5 | MAT4-OP-70-5-FY09 | 963 | 0.1575 | Rupture |
| Average | | 1,013 | 0.1438 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) Reference G-116 thru G-120 for individual specimen data.
- 2) 8 specimens tested, group of 5 specimens with representative data to report.
- 3) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 4) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-1-70-FY09**
 Test Date: 6/10/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

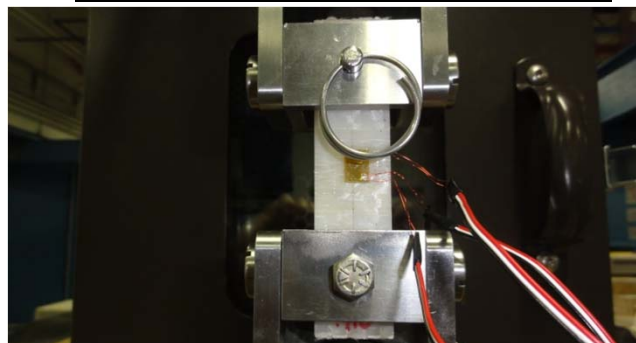
Maximum Load, P_z : 887 lbs
 Poisson's Ratio, v_{xz} : 0.1242

Measured Specimen Dimensions:

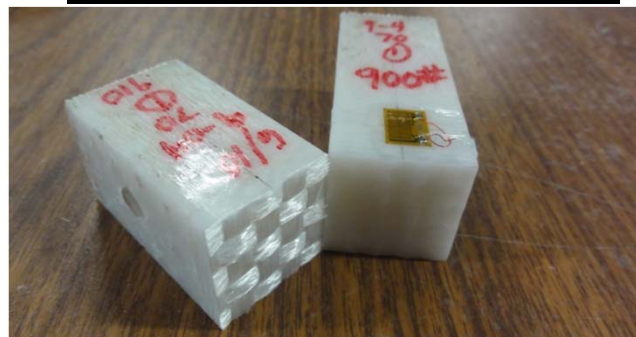
Thickness: 0.902 in
 Side 1: 0.910 in
 Side 2: 0.910 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 443 lbs
 20% Max Load: 177 lbs

PICTURE OF SPECIMEN PRE-TEST

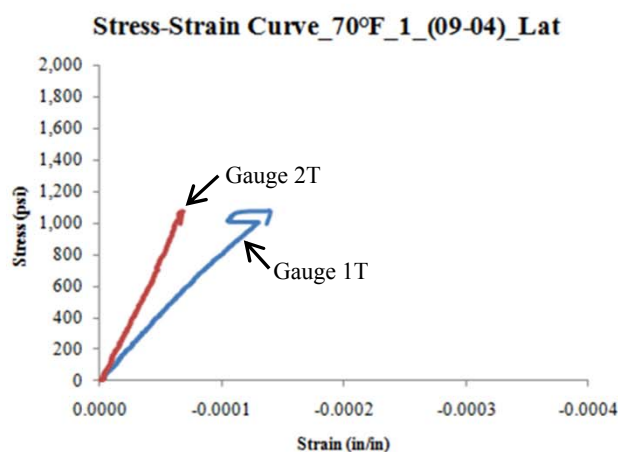
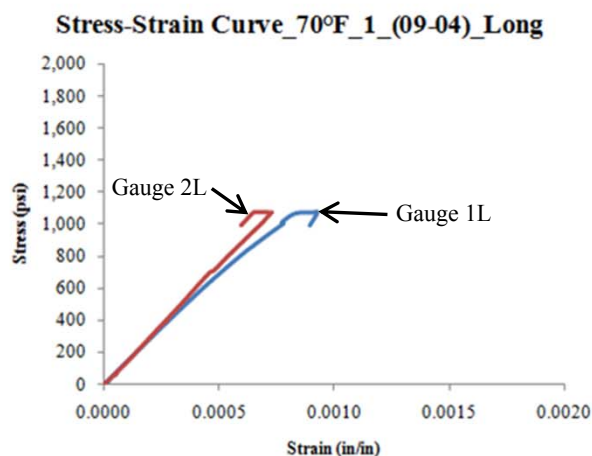


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000384 | 0.000149 | 1T | -0.000063 | -0.000027 | 0.1570 |
| 2L | 0.000359 | 0.000149 | 2T | -0.000036 | -0.000016 | 0.0915 |
| Average | | | | | | 0.1242 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-2-70-FY09**
 Test Date: 6/10/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

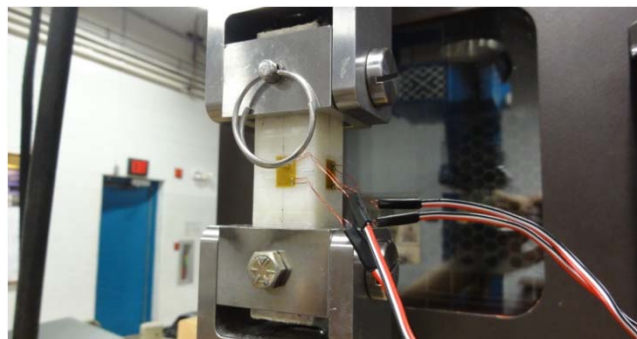
Maximum Load, P_z : 1,162 lbs
 Poisson's Ratio, v_{xz} : 0.1257

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.907 in
 Side 2: 0.907 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 581 lbs
 20% Max Load: 232 lbs

PICTURE OF SPECIMEN PRE-TEST

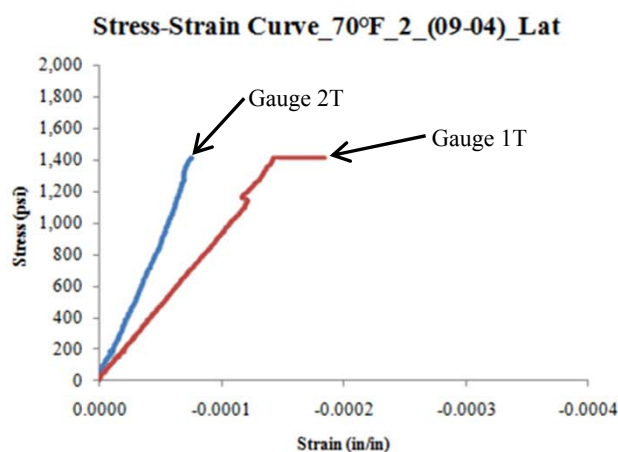
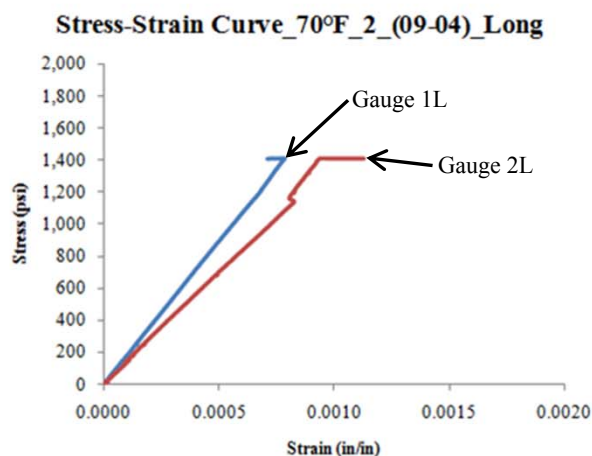


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000392 | 0.000155 | 1T | -0.000040 | -0.000016 | 0.1018 |
| 2L | 0.000501 | 0.000193 | 2T | -0.000076 | -0.000029 | 0.1496 |
| Average | | | | | | 0.1257 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-3-70-FY09**
 Test Date: 6/13/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

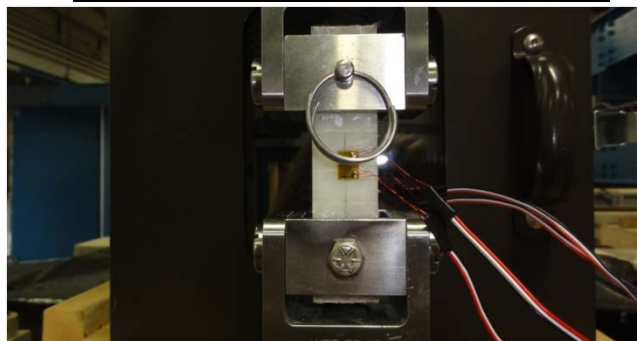
Maximum Load, P_z : 1,048 lbs
 Poisson's Ratio, v_{xz} : 0.1556

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.910 in
 Side 2: 0.907 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 524 lbs
 20% Max Load: 210 lbs

PICTURE OF SPECIMEN PRE-TEST

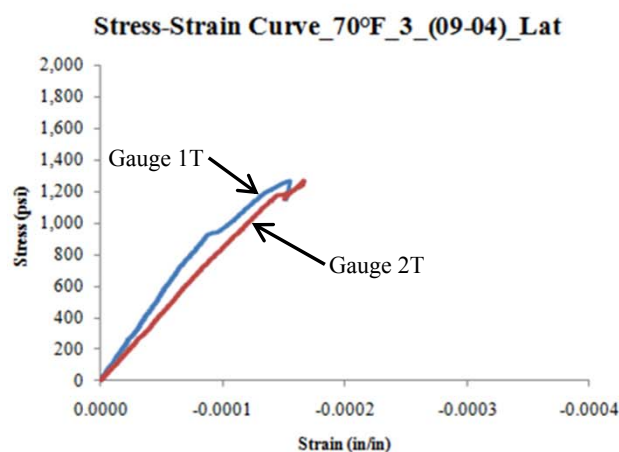
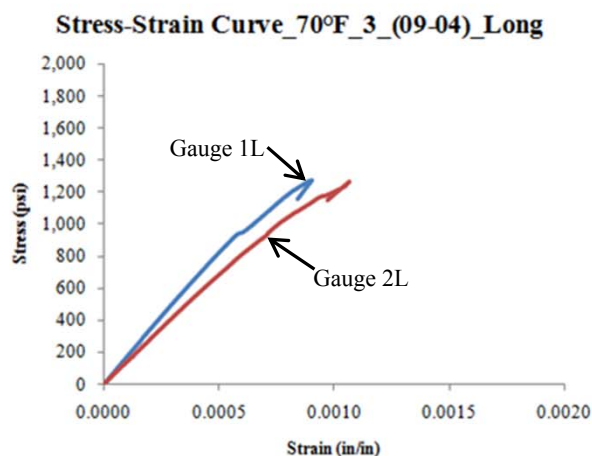


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000381 | 0.000149 | 1T | -0.000058 | -0.000023 | 0.1508 |
| 2L | 0.000458 | 0.000181 | 2T | -0.000074 | -0.000030 | 0.1603 |
| Average | | | | | | 0.1556 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-4-70-FY09**
 Test Date: 6/13/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

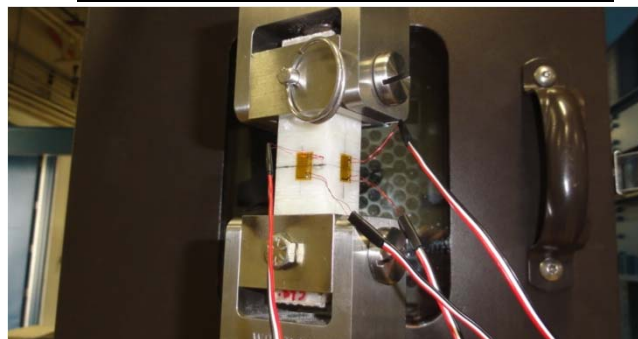
Maximum Load, P_z : 954 lbs
 Poisson's Ratio, v_{xz} : 0.1560

Measured Specimen Dimensions:

Thickness: 0.901 in
 Side 1: 0.878 in
 Side 2: 0.880 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 477 lbs
 20% Max Load: 191 lbs

PICTURE OF SPECIMEN PRE-TEST

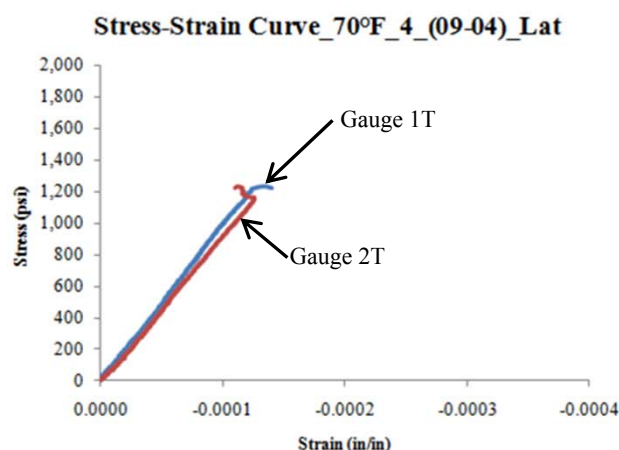
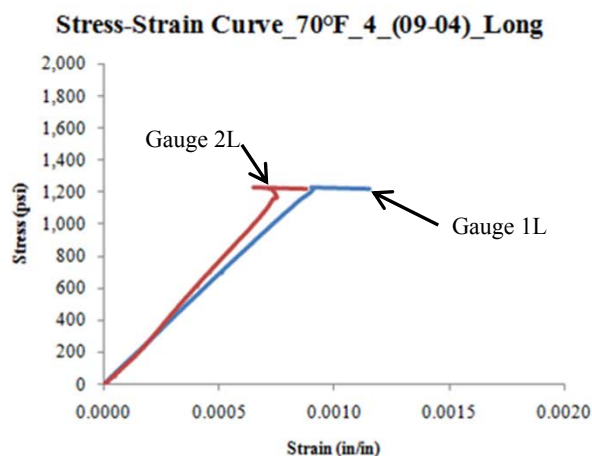


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000444 | 0.000178 | 1T | -0.000063 | -0.000026 | 0.1389 |
| 2L | 0.000401 | 0.000180 | 2T | -0.000068 | -0.000030 | 0.1731 |
| Average | | | | | | 0.1560 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-5-70-FY09**
 Test Date: 6/13/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

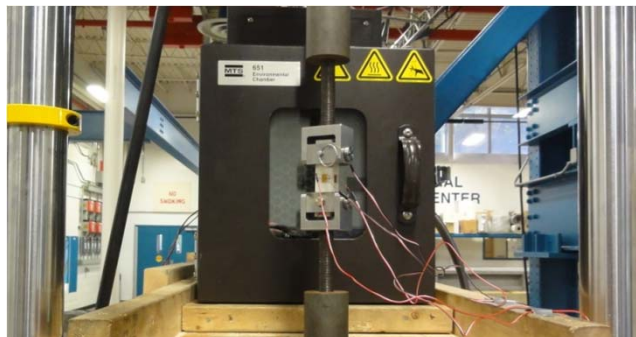
Maximum Load, P_z : 963 lbs
 Poisson's Ratio, v_{xz} : 0.1905

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.905 in
 Side 2: 0.908 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 481 lbs
 20% Max Load: 193 lbs

PICTURE OF SPECIMEN PRE-TEST



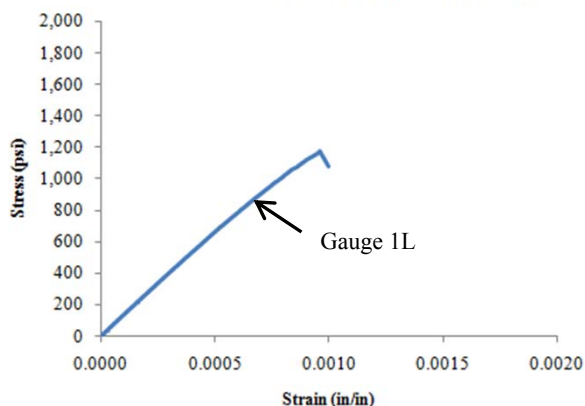
PICTURE OF SPECIMEN POST-TEST



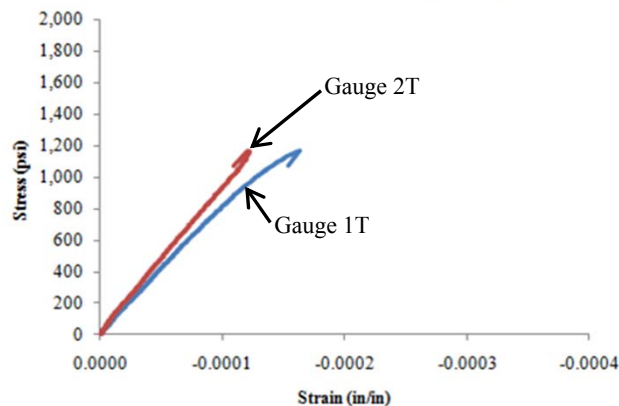
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gages | | | Lateral Gages | | | Poisson's Ratio v_{xz} |
|--------------------|-------------------------------------|-------------------------------------|---------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000442 | 0.000173 | 1T | -0.000070 | -0.000027 | 0.1575 |
| 2L | Lost Gauge | | 2T | -0.000060 | -0.000023 | - |
| Average | | | | | | 0.1575 |

Stress-Strain Curve_70°F_5_(09-04)_Long



Stress-Strain Curve_70°F_5_(09-04)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

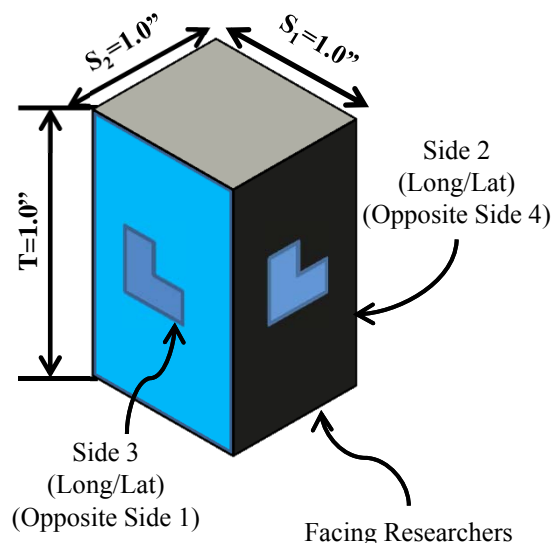
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT4-OP-140-FY09
Material: Huntsman Epoxy Resin SC-15, S2 Glass
Nominal Temperature: 140°F
Properties Measured:
Average Material Properties (5 Specimens):
Poisson’s Ratio, ν_{xz} : 0.1471
Maximum Load, P_z : 1,069 lbs

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT4-OP-140-1-FY09 | 823 | 0.1189 | Rupture |
| 2 | MAT4-OP-140-2-FY09 | 1,003 | 0.1457 | Rupture |
| 3 | MAT4-OP-140-3-FY09 | 1,228 | 0.1593 | Rupture |
| 4 | MAT4-OP-140-4-FY09 | 1,089 | 0.1516 | Rupture |
| 5 | MAT4-OP-140-5-FY09 | 1,200 | 0.1602 | Pin tear out |
| Average | | 1,069 | 0.1471 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 1”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference G-122 thru G-126 for individual specimen data.
- 2) 7 specimens tested, group of 5 specimens with representative data to report.
- 3) Rupture failure refers to ASTM failure greater than 1 ply from the epoxied specimen at the base.
- 4) Pin tear out refers to a failure in the specimen where the pin teared through.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-1-140-FY09**
 Test Date: 6/13/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

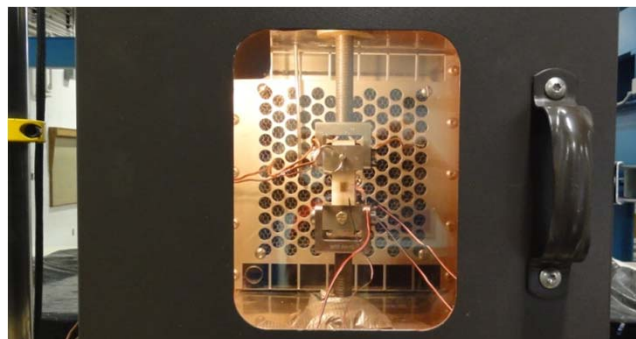
Maximum Load, P_z : 823 lbs
 Poisson's Ratio, v_{xz} : 0.1189

Measured Specimen Dimensions:

Thickness: 0.904 in
 Side 1: 0.905 in
 Side 2: 0.909 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 412 lbs
 20% Max Load: 165 lbs

PICTURE OF SPECIMEN PRE-TEST

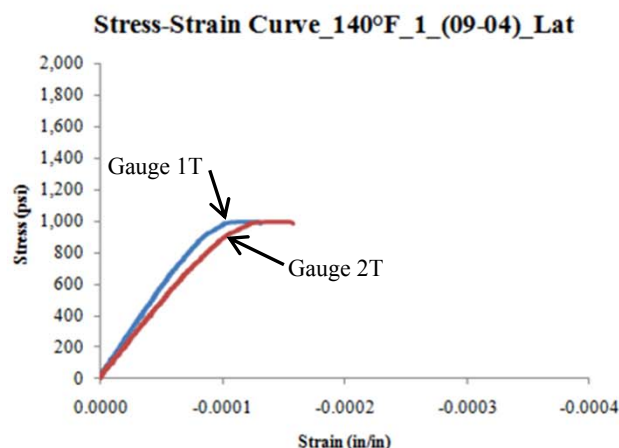
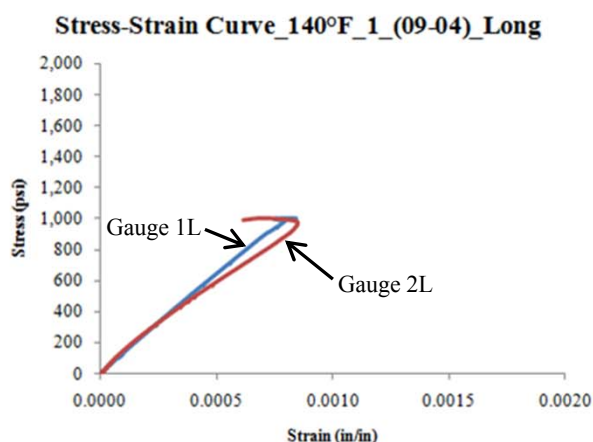


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000382 | 0.000149 | 1T | -0.000043 | -0.000016 | 0.1166 |
| 2L | 0.000409 | 0.000140 | 2T | -0.000052 | -0.000019 | 0.1212 |
| Average | | | | | | 0.1189 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-2-140-FY09**
 Test Date: 6/14/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

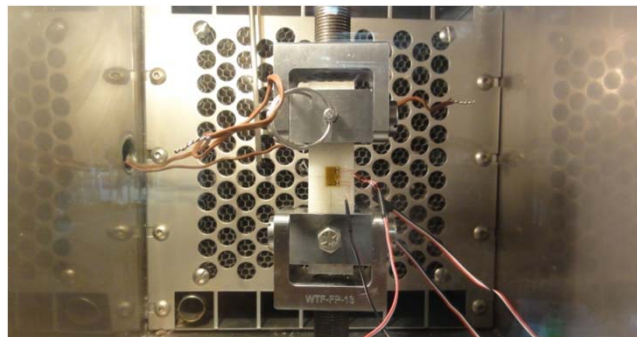
Average Material Properties:

Maximum Load, P_z : 1,003 lbs
 Poisson's Ratio, v_{xz} : 0.1457

Measured Specimen Dimensions:

Thickness: 0.904 in
 Side 1: 0.907 in
 Side 2: 0.909 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 502 lbs
 20% Max Load: 201 lbs

PICTURE OF SPECIMEN PRE-TEST

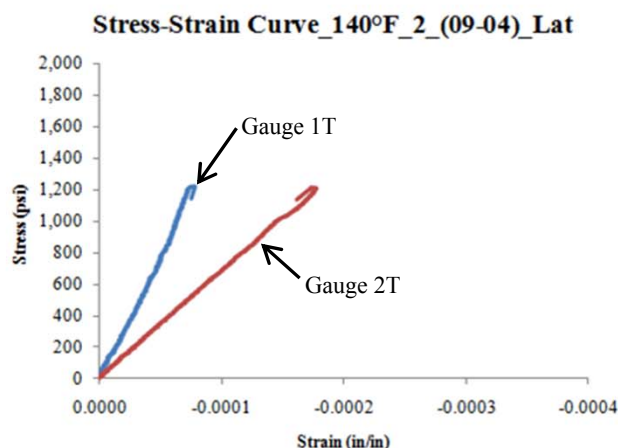
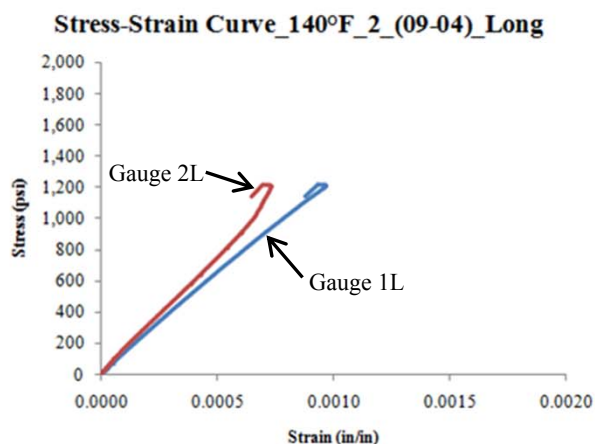


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000462 | 0.000177 | 1T | -0.000040 | -0.000017 | 0.0810 |
| 2L | 0.000404 | 0.000149 | 2T | -0.000088 | -0.000034 | 0.2104 |
| Average | | | | | | 0.1457 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-3-140-FY09**
 Test Date: 6/15/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

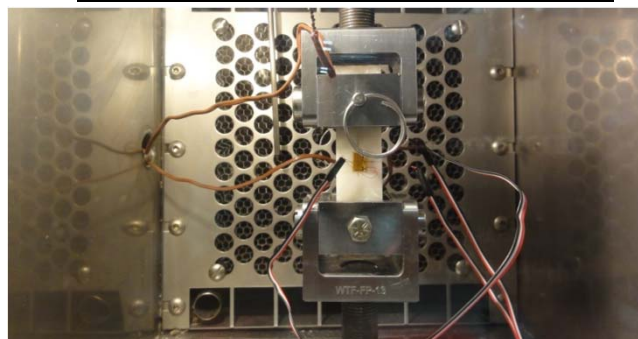
Average Material Properties:

Maximum Load, P_z : 1,228 lbs
 Poisson's Ratio, v_{xz} : 0.1593

Measured Specimen Dimensions:

Thickness: 0.903 in
 Side 1: 0.992 in
 Side 2: 0.992 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 614 lbs
 20% Max Load: 246 lbs

PICTURE OF SPECIMEN PRE-TEST

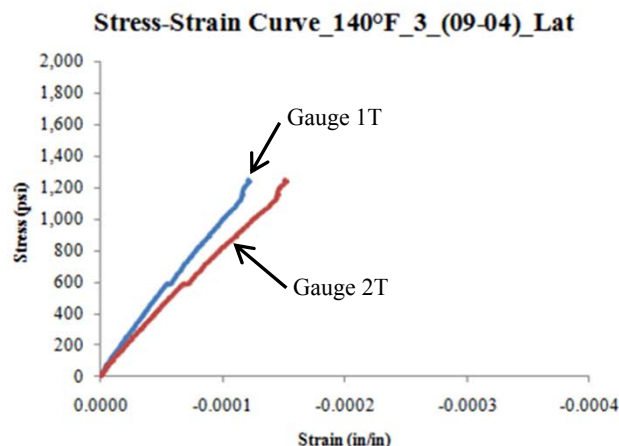
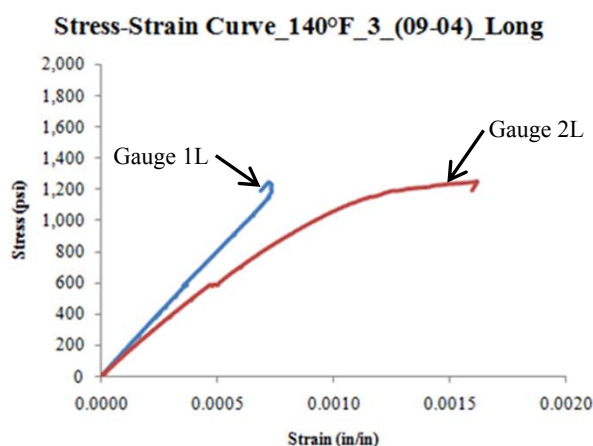


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000379 | 0.000150 | 1T | -0.000061 | -0.000021 | 0.1732 |
| 2L | 0.000526 | 0.000185 | 2T | -0.000076 | -0.000026 | 0.1453 |
| Average | | | | | | 0.1593 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-4-140-FY09**
 Test Date: 6/14/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

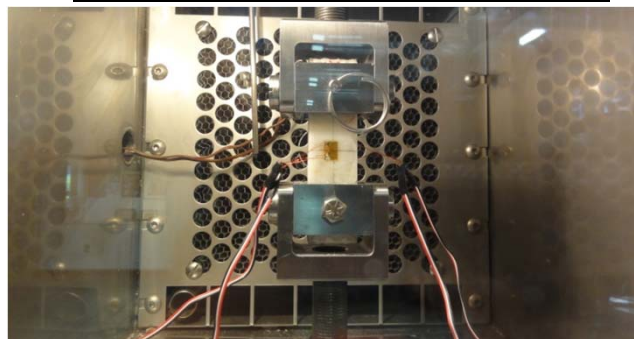
Average Material Properties:

Maximum Load, P_z : 1,089 lbs
 Poisson's Ratio, v_{xz} : 0.1516

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.992 in
 Side 2: 0.992 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 545 lbs
 20% Max Load: 218 lbs

PICTURE OF SPECIMEN PRE-TEST

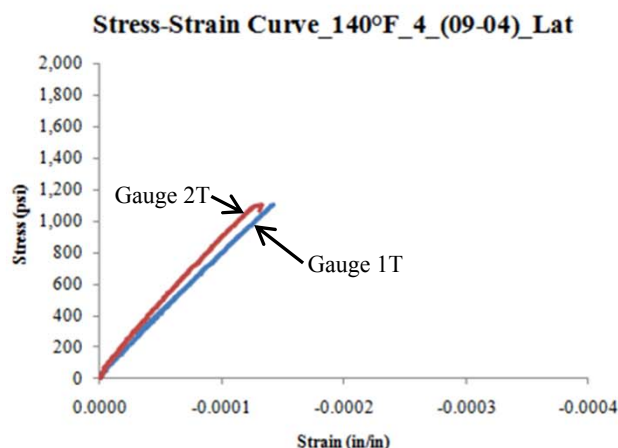
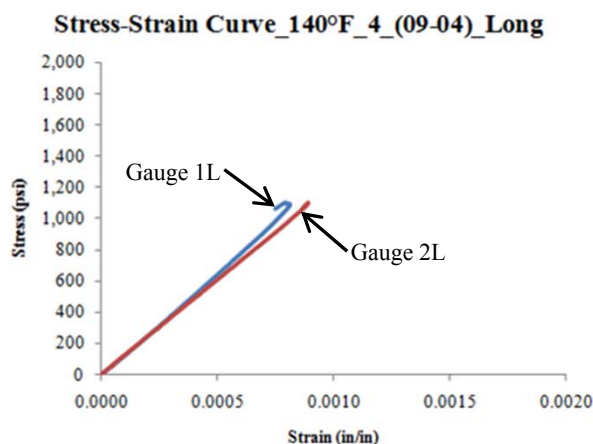


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000433 | 0.000182 | 1T | -0.000067 | -0.000026 | 0.1658 |
| 2L | 0.000454 | 0.000180 | 2T | -0.000057 | -0.000020 | 0.1374 |
| Average | | | | | | 0.1516 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT4-OP-5-140-FY09**
 Test Date: 6/15/2011
 Specimen Received: 5/27/2011
 Properties Measured: v_{xz}

Average Material Properties:

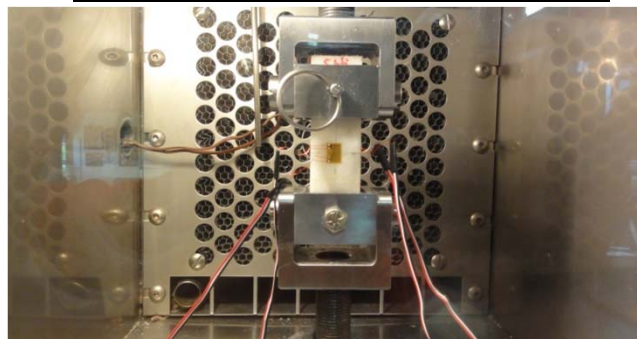
Maximum Load, P_z : 1,200 lbs
 Poisson's Ratio, v_{xz} : 0.1602

Measured Specimen Dimensions:

Thickness: 0.902 in
 Side 1: 0.994 in
 Side 2: 0.993 in

Laboratory Temperature: 68°F
 Failure Mode: Pin Pull-Out
 50% Max Load: 600 lbs
 20% Max Load: 240 lbs

PICTURE OF SPECIMEN PRE-TEST

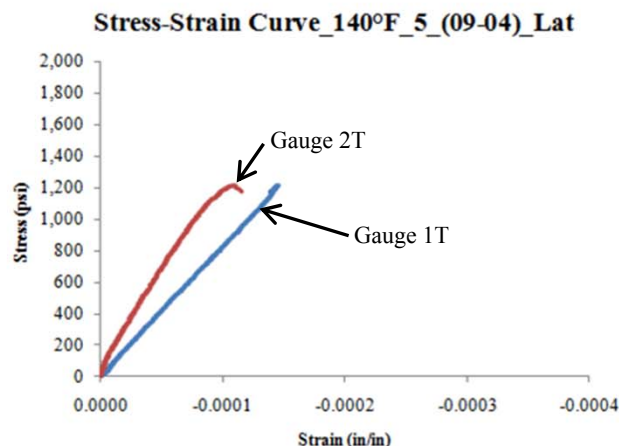
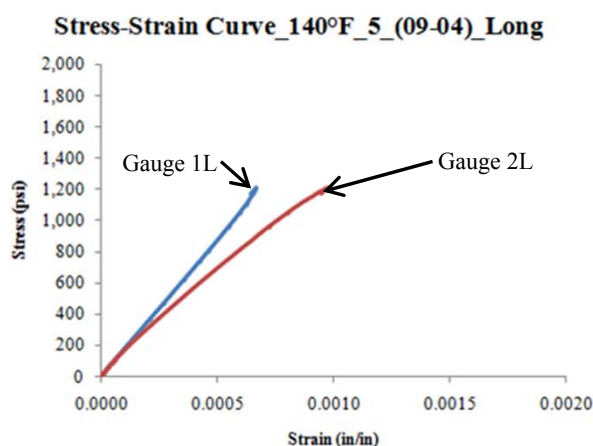


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio v_{xz} |
|---------------------|-------------------------------------|-------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | |
| 1L | 0.000347 | 0.000136 | 1T | -0.000073 | -0.000028 | 0.2133 |
| 2L | 0.000427 | 0.000150 | 2T | -0.000044 | -0.000014 | 0.1071 |
| Average | | | | | | 0.1602 |



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides.
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX H

MATERIAL 5-FY09 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-TX-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 18,495 | lbs |
| Tensile Strength, ST_x : | 46,837 | psi |
| Tensile Modulus, E_x : | 2,309,264 | psi |
| Ultimate Strain, ϵ_x : | 0.0203 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2422 | |

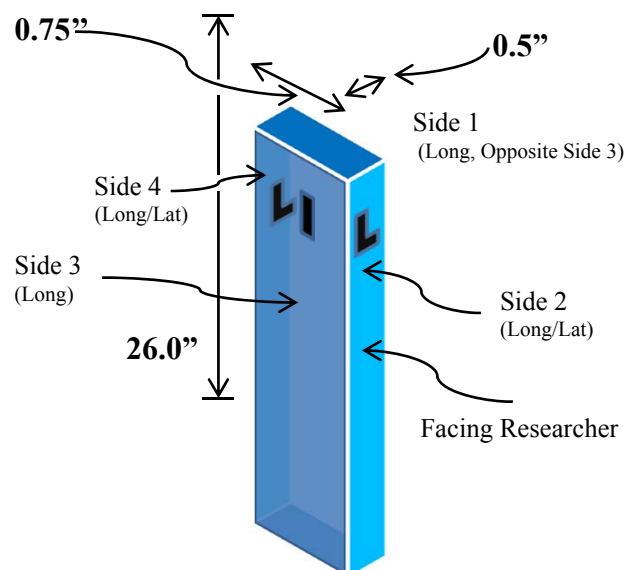
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT5-TX-1-N40-FY09 | 20,282 | 49,237 | 2,282,045 | 0.0216 | 0.2039 | DGM |
| 2 | MAT5-TX-2-N40-FY09 | 18,523 | 47,080 | 2,332,199 | 0.0202 | 0.2501 | DGM |
| 3 | MAT5-TX-3-N40-FY09 | 17,852 | 45,752 | 2,303,392 | 0.0199 | 0.2373 | DGM |
| 4 | MAT5-TX-4-N40-FY09 | 18,643 | 48,415 | 2,308,663 | 0.0210 | 0.2223 | DGM |
| 5 | MAT5-TX-5-N40-FY09 | 17,175 | 43,701 | 2,320,023 | 0.0188 | 0.2972 | DGM |
| Average | | 18,495 | 46,837 | 2,309,264 | 0.0203 | 0.2422 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See H-2 to H-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-1-N40-FY09**
 Test Date: 9/20/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 20,282 lbs
 Tensile Strength, ST_x : 49,237 psi
 Tensile Modulus, E_x : 2,282,045 psi
 Ultimate Strain, ϵ_x : 0.0216 in/in
 Poisson's Ratio, ν_{xy} : 0.2039

Measured Specimen Dimensions:

Width, W: 0.5208 in
 Thickness, H: 0.7910 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 4,056 lbs
 50% Max Load: 10,141 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

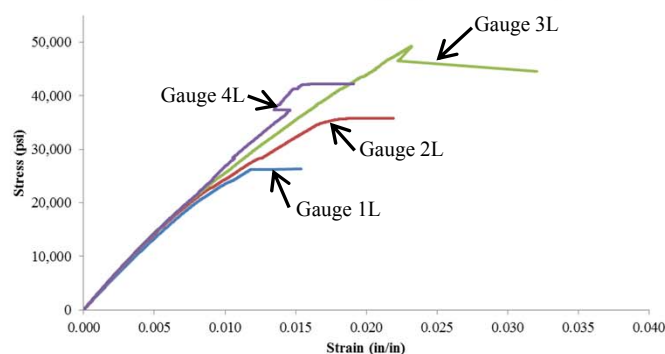


PICTURE OF SPECIMEN POST-TEST

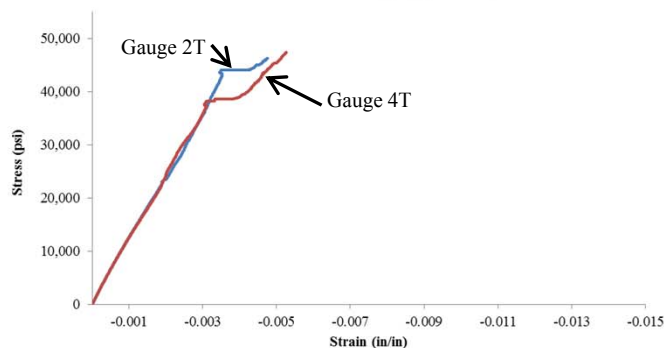


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0108 | 0.0036 | 2,042,064 | | | | |
| 2L | 0.0102 | 0.0034 | 2,171,294 | 2T | -0.0021 | -0.0008 | 0.1959 |
| 3L | 0.0095 | 0.0033 | 2,396,551 | | | | |
| 4L | 0.0092 | 0.0033 | 2,518,271 | 4T | -0.0020 | -0.0008 | 0.2120 |
| Average | | | 2,282,045 | | | | 0.2039 |

Stress-Strain Curve N40_1_(09-05), Long.



Stress-Strain Curve N40_1_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-2-N40-FY09**
 Test Date: 9/20/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

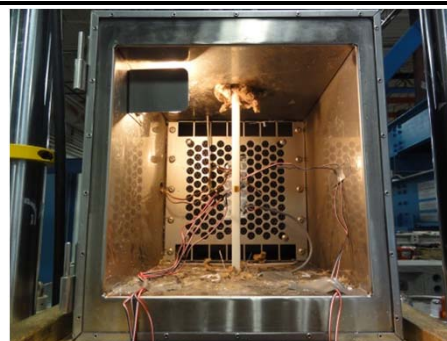
Ultimate Load, P_x : 18,523 lbs
 Tensile Strength, ST_x : 47,080 psi
 Tensile Modulus, E_x : 2,332,199 psi
 Ultimate Strain, ϵ_x : 0.0202 in/in
 Poisson's Ratio, v_{xy} : 0.2501

Measured Specimen Dimensions:

Width, W: 0.4952 in
 Thickness, H: 0.7945 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,705 lbs
 50% Max Load: 9,262 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

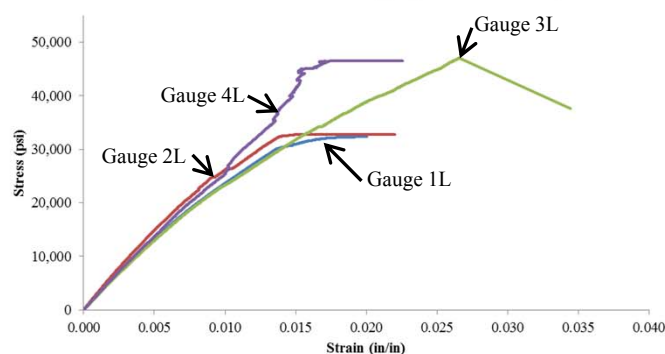


PICTURE OF SPECIMEN POST-TEST

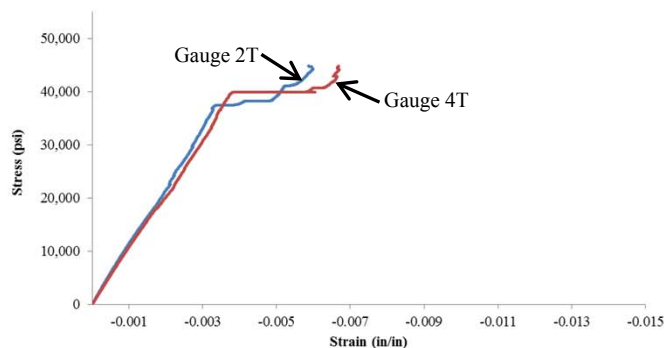


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0099 | 0.0035 | 2,179,808 | | | | |
| 2L | 0.0085 | 0.0030 | 2,570,372 | 2T | -0.0022 | -0.0008 | 0.2460 |
| 3L | 0.0102 | 0.0035 | 2,131,992 | | | | |
| 4L | 0.0091 | 0.0033 | 2,446,625 | 4T | -0.0023 | -0.0009 | 0.2542 |
| Average | | | 2,332,199 | | | | 0.2501 |

Stress-Strain Curve N40_2_(09-05), Long.



Stress-Strain Curve N40_2_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-3-N40-FY09**
 Test Date: 9/21/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 17,852 lbs
 Tensile Strength, ST_x : 45,752 psi
 Tensile Modulus, E_x : 2,303,392 psi
 Ultimate Strain, ϵ_x : 0.0199 in/in
 Poisson's Ratio, v_{xy} : 0.2373

Measured Specimen Dimensions:

Width, W : 0.4921 in
 Thickness, H : 0.7929 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,570 lbs
 50% Max Load: 8,926 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

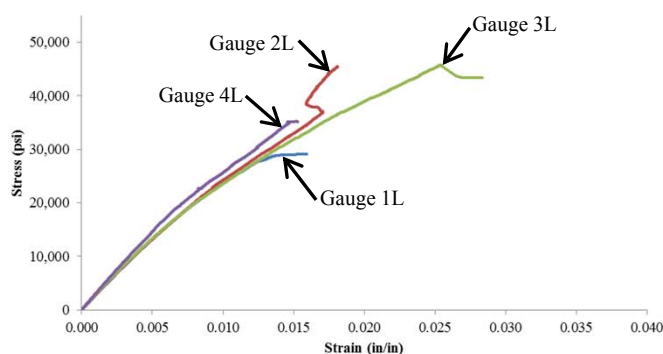


PICTURE OF SPECIMEN POST-TEST

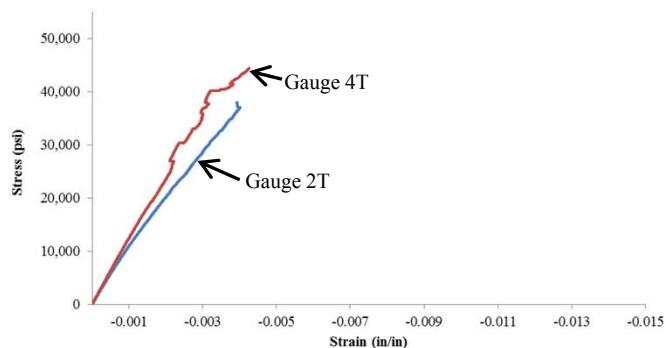


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0096 | 0.0034 | 2,214,525 | | | | |
| 2L | 0.0093 | 0.0033 | 2,320,627 | 2T | -0.0023 | -0.0008 | 0.2518 |
| 3L | 0.0096 | 0.0033 | 2,170,629 | | | | |
| 4L | 0.0085 | 0.0030 | 2,507,787 | 4T | -0.0019 | -0.0007 | 0.2228 |
| Average | | | 2,303,392 | | | | 0.2373 |

Stress-Strain Curve N40_3_(09-05), Long.



Stress-Strain Curve N40_3_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-4-N40-FY09**
 Test Date: 9/21/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

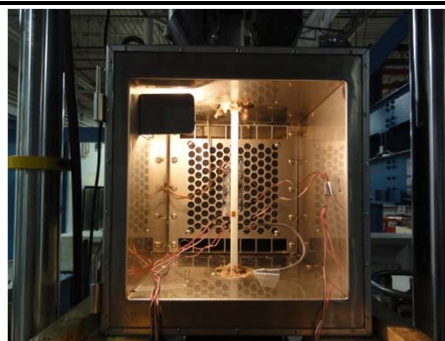
Ultimate Load, P_x : 18,643 lbs
 Tensile Strength, ST_x : 48,415 psi
 Tensile Modulus, E_x : 2,308,663 psi
 Ultimate Strain, ϵ_x : 0.0210 in/in
 Poisson's Ratio, v_{xy} : 0.2223

Measured Specimen Dimensions:

Width, W: 0.4921 in
 Thickness, H: 0.7825 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,729 lbs
 50% Max Load: 9,322 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

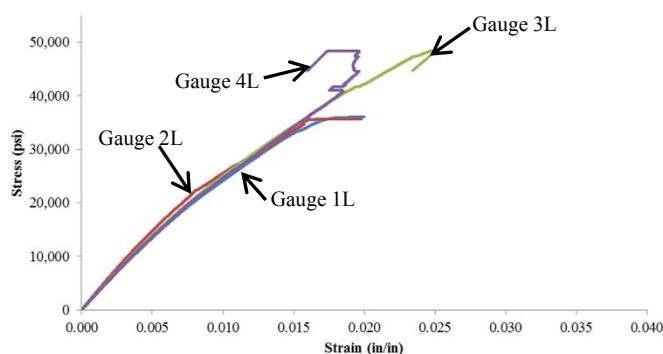


PICTURE OF SPECIMEN POST-TEST

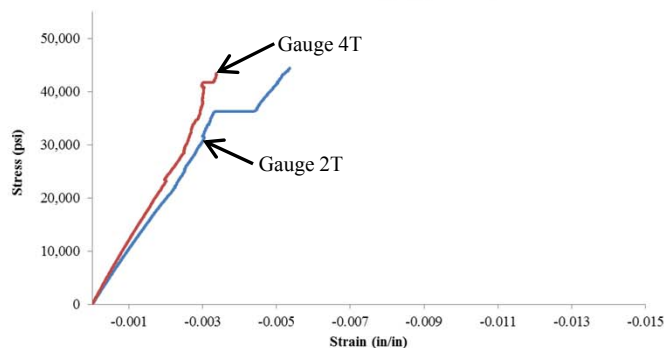


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0100 | 0.0035 | 2,222,299 | | | | |
| 2L | 0.0092 | 0.0031 | 2,379,712 | 2T | -0.0024 | -0.0009 | 0.2478 |
| 3L | 0.0096 | 0.0034 | 2,345,506 | | | | |
| 4L | 0.0098 | 0.0034 | 2,287,137 | 4T | -0.0020 | -0.0008 | 0.1967 |
| Average | | | 2,308,663 | | | | 0.2223 |

Stress-Strain Curve N40_4_(09-05), Long.



Stress-Strain Curve N40_4_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-5-N40-FY09**
 Test Date: 9/21/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 17,175 lbs
 Tensile Strength, ST_x : 43,701 psi
 Tensile Modulus, E_x : 2,320,023 psi
 Ultimate Strain, ϵ_x : 0.0188 in/in
 Poisson's Ratio, v_{xy} : 0.2972

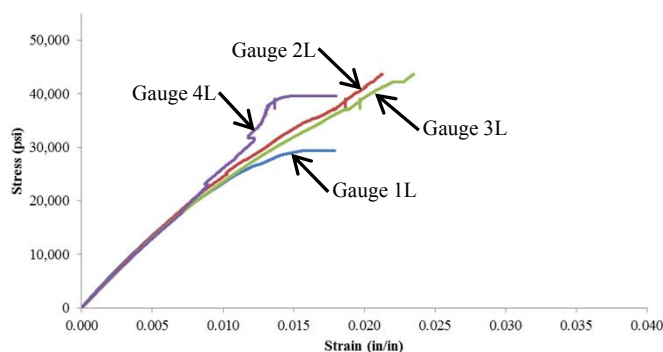
Measured Specimen Dimensions:

Width, W: 0.4946 in
 Thickness, H: 0.7946 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,435 lbs
 50% Max Load: 8,587 lbs

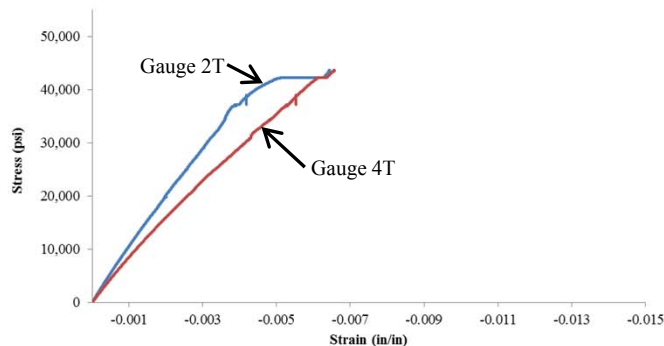
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0092 | 0.0031 | 2,153,102 | | | | |
| 2L | 0.0086 | 0.0031 | 2,387,429 | 2T | -0.0022 | -0.0008 | 0.2495 |
| 3L | 0.0091 | 0.0033 | 2,244,851 | | | | |
| 4L | 0.0085 | 0.0033 | 2,494,710 | 4T | -0.0028 | -0.0010 | 0.3449 |
| Average | | | 2,320,023 | | | | 0.2972 |

Stress-Strain Curve N40_5_(09-05), Long.



Stress-Strain Curve N40_5_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-TX-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: ST_x , E_x , ν_{xy}

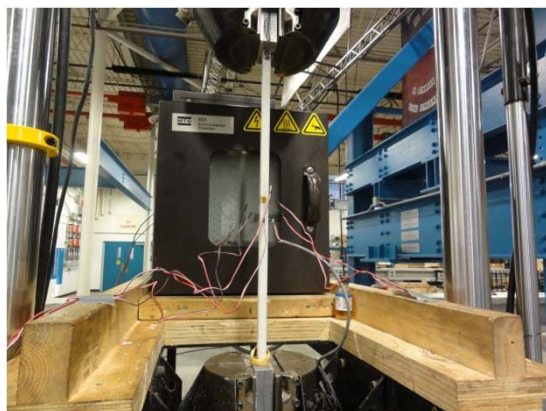
Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 17,829 | lbs |
| Tensile Strength, ST_x : | 45,551 | psi |
| Tensile Modulus, E_x : | 2,018,540 | psi |
| Ultimate Strain, ϵ_x : | 0.0226 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2644 | |

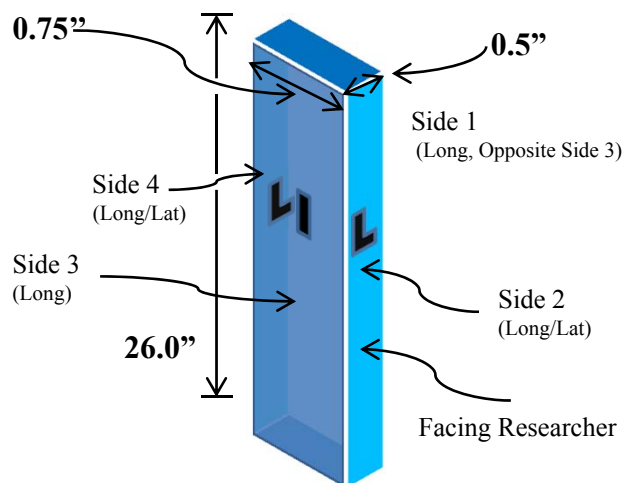
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|-------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT5-TX-70-FY09-1 | 17,326 | 44,417 | 2,158,676 | 0.0206 | 0.2328 | DGM |
| 2 | MAT5-TX-70-FY09-2 | 18,150 | 45,310 | 2,012,251 | 0.0225 | 0.2035 | DGM |
| 3 | MAT5-TX-70-FY09-3 | 18,282 | 46,732 | 1,926,402 | 0.0243 | 0.3139 | DGM |
| 4 | MAT5-TX-70-FY09-4 | 17,348 | 44,167 | 1,942,245 | 0.0227 | 0.2789 | DGM |
| 5 | MAT5-TX-70-FY09-5 | 18,040 | 47,131 | 2,053,123 | 0.0230 | 0.2931 | DGM |
| Average | | 17,829 | 45,551 | 2,018,540 | 0.0226 | 0.2644 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See H-8 to H-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-1-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

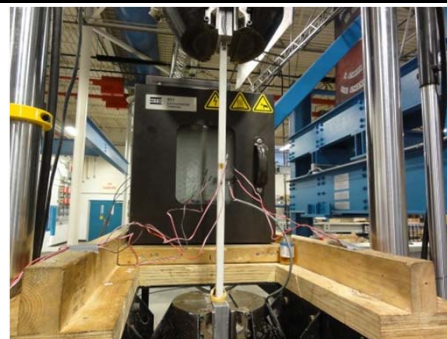
Ultimate Load, P_x : 17,326 lbs
 Tensile Strength, ST_x : 44,417 psi
 Tensile Modulus, E_x : 2,158,676 psi
 Ultimate Strain, ϵ_x : 0.0206 in/in
 Poisson's Ratio, v_{xy} : 0.2328

Measured Specimen Dimensions:

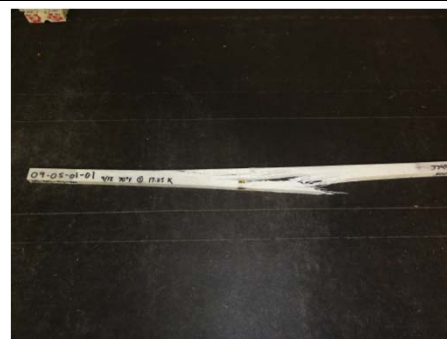
Width, W: 0.5004 in
 Thickness, H: 0.7795 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,465 lbs
 50% Max Load: 8,663 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

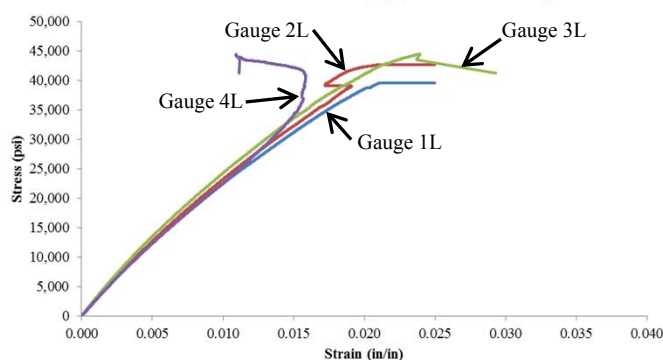


PICTURE OF SPECIMEN POST-TEST

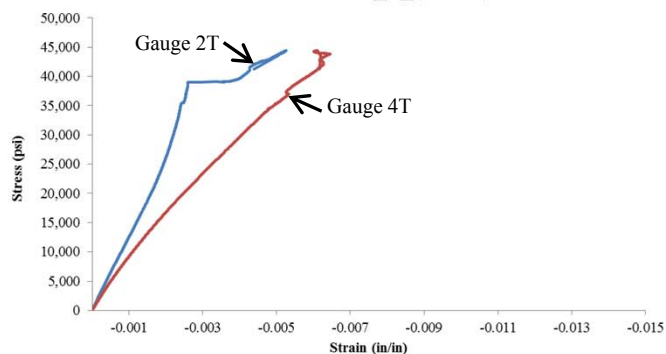


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0098 | 0.0035 | 2,084,558 | | | | |
| 2L | 0.0095 | 0.0034 | 2,183,202 | 2T | -0.0018 | -0.0007 | 0.1731 |
| 3L | 0.0090 | 0.0031 | 2,271,071 | | | | |
| 4L | 0.0098 | 0.0035 | 2,095,874 | 4T | -0.0028 | -0.0010 | 0.2924 |
| Average | | | 2,158,676 | | | | 0.2328 |

Stress-Strain Curve 70_1_(09-05), Long.



Stress-Strain Curve 70_1_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-2-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 18,150 lbs
 Tensile Strength, ST_x : 45,310 psi
 Tensile Modulus, E_x : 2,012,251 psi
 Ultimate Strain, ϵ_x : 0.0225 in/in
 Poisson's Ratio, v_{xy} : 0.2035

Measured Specimen Dimensions:

Width, W: 0.5092 in
 Thickness, H: 0.7867 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,630 lbs
 50% Max Load: 9,075 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

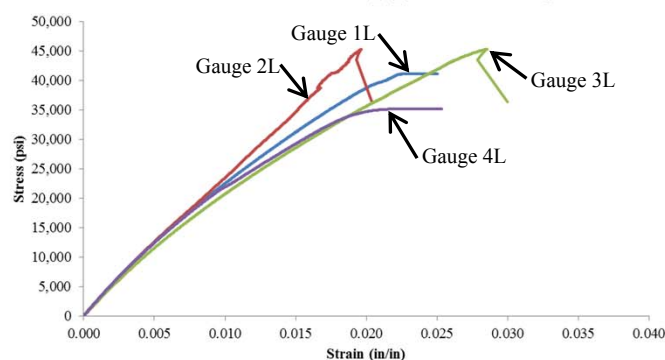


PICTURE OF SPECIMEN POST-TEST

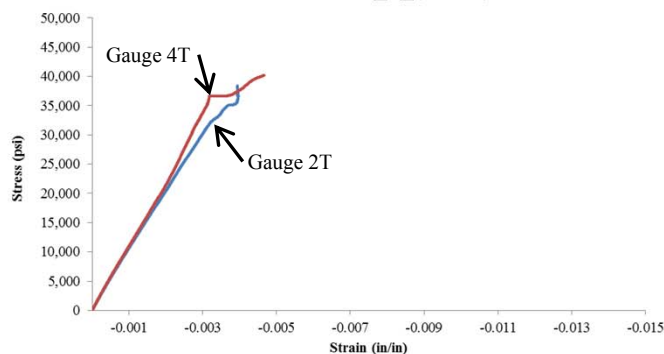


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0101 | 0.0035 | 2,065,963 | | | | |
| 2L | 0.0096 | 0.0035 | 2,212,571 | 2T | -0.0022 | -0.0008 | 0.2241 |
| 3L | 0.0112 | 0.0038 | 1,845,356 | | | | |
| 4L | 0.0106 | 0.0035 | 1,925,114 | 4T | -0.0021 | -0.0008 | 0.1830 |
| Average | | | 2,012,251 | | | | 0.2035 |

Stress-Strain Curve 70_2_(09-05), Long.



Stress-Strain Curve 70_2_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-3-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 18,282 lbs
 Tensile Strength, ST_x : 46,732 psi
 Tensile Modulus, E_x : 1,926,402 psi
 Ultimate Strain, ϵ_x : 0.0243 in/in
 Poisson's Ratio, v_{xy} : 0.3139

Measured Specimen Dimensions:

Width, W: 0.4986 in
 Thickness, H: 0.7846 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,656 lbs
 50% Max Load: 9,141 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

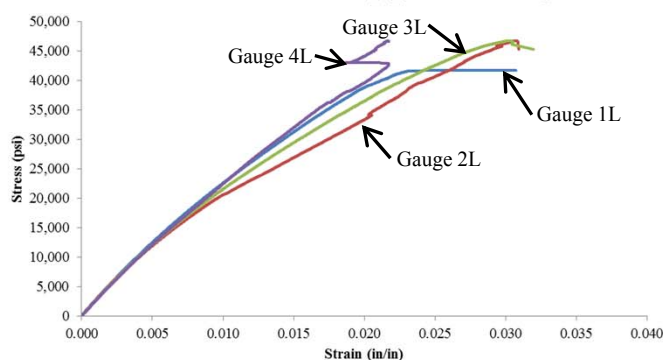


PICTURE OF SPECIMEN POST-TEST

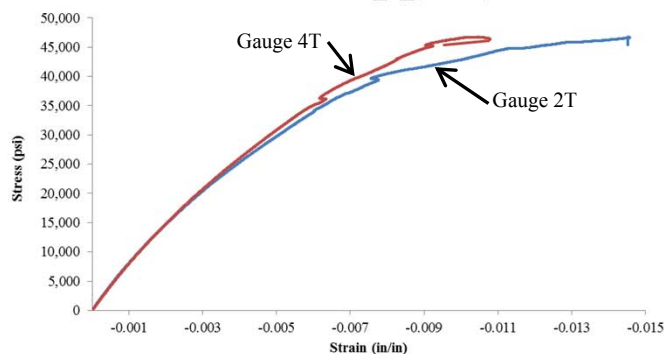


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0104 | 0.0036 | 2,055,352 | | | | |
| 2L | 0.0122 | 0.0038 | 1,653,706 | 2T | -0.0036 | -0.0012 | 0.2846 |
| 3L | 0.0111 | 0.0037 | 1,903,291 | | | | |
| 4L | 0.0105 | 0.0038 | 2,093,259 | 4T | -0.0035 | -0.0012 | 0.3432 |
| Average | | | 1,926,402 | | | | 0.3139 |

Stress-Strain Curve 70_3_(09-05), Long.



Stress-Strain Curve 70_3_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-4-70-FY09**
 Test Date: 9/13/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 17,348 lbs
 Tensile Strength, ST_x : 44,167 psi
 Tensile Modulus, E_x : 1,942,245 psi
 Ultimate Strain, ϵ_x : 0.0227 in/in
 Poisson's Ratio, ν_{xy} : 0.2789

Measured Specimen Dimensions:

Width, W: 0.4994 in
 Thickness, H: 0.7865 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,470 lbs
 50% Max Load: 8,674 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

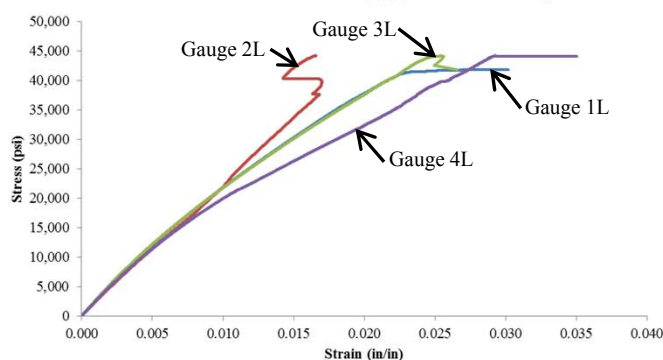


PICTURE OF SPECIMEN POST-TEST

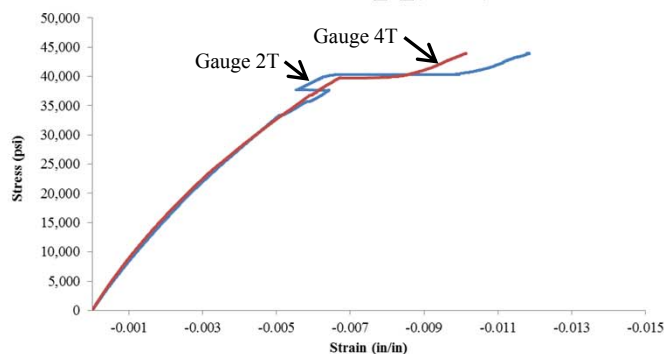


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0101 | 0.0035 | 2,003,356 | | | | |
| 2L | 0.0101 | 0.0038 | 2,113,042 | 2T | -0.0030 | -0.0011 | 0.3125 |
| 3L | 0.0102 | 0.0035 | 1,977,289 | | | | |
| 4L | 0.0116 | 0.0037 | 1,675,292 | 4T | -0.0029 | -0.0010 | 0.2452 |
| Average | | | 1,942,245 | | | | 0.2789 |

Stress-Strain Curve 70_4_(09-05), Long.



Stress-Strain Curve 70_4_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-5-70-FY09**
 Test Date: 9/13/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 18,040 lbs
 Tensile Strength, ST_x : 47,131 psi
 Tensile Modulus, E_x : 2,053,123 psi
 Ultimate Strain, ϵ_x : 0.0230 in/in
 Poisson's Ratio, v_{xy} : 0.2931

Measured Specimen Dimensions:

Width, W: 0.4896 in
 Thickness, H: 0.7818 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,608 lbs
 50% Max Load: 9,020 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

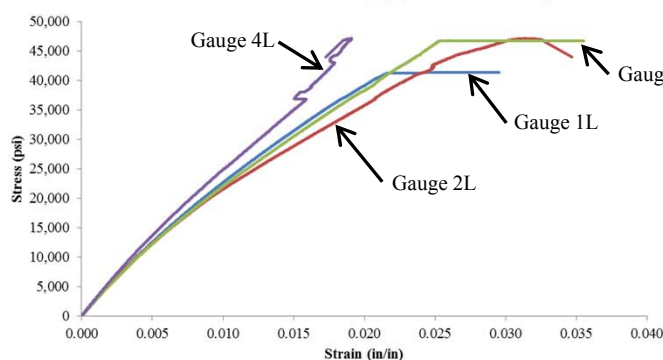


PICTURE OF SPECIMEN POST-TEST

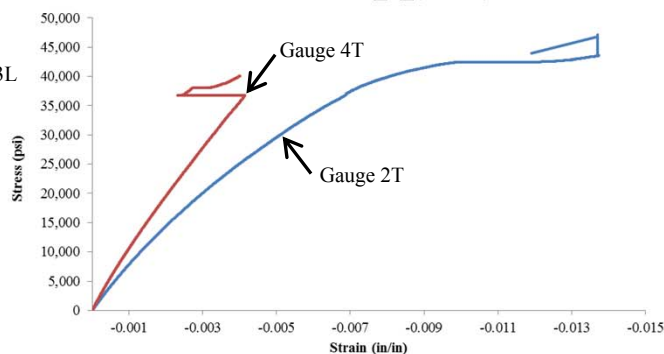


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0105 | 0.0036 | 2,062,447 | | | | |
| 2L | 0.0113 | 0.0037 | 1,846,223 | 2T | -0.0037 | -0.0012 | 0.3215 |
| 3L | 0.0109 | 0.0037 | 1,977,560 | | | | |
| 4L | 0.0094 | 0.0033 | 2,326,263 | 4T | -0.0025 | -0.0009 | 0.2647 |
| Average | | | 2,053,123 | | | | 0.2931 |

Stress-Strain Curve 70_5_(09-05), Long.



Stress-Strain Curve 70_5_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-TX-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 14,887 | lbs |
| Tensile Strength, ST_x : | 38,130 | psi |
| Tensile Modulus, E_x : | 1,910,698 | psi |
| Ultimate Strain, ϵ_x : | 0.0200 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.2159 | |

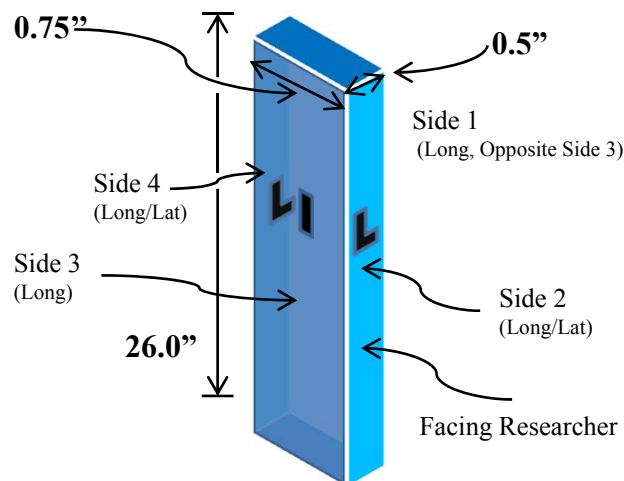
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT5-TX-1-140-FY09 | 14,874 | 38,133 | 1,939,161 | 0.0197 | 0.2744 | DGM |
| 2 | MAT5-TX-2-140-FY09 | 15,226 | 39,035 | 1,945,621 | 0.0201 | 0.1820 | DGM |
| 3 | MAT5-TX-3-140-FY09 | 15,180 | 38,917 | 1,873,748 | 0.0208 | 0.1773 | DGM |
| 4 | MAT5-TX-4-140-FY09 | 14,048 | 36,015 | 1,822,834 | 0.0198 | 0.2325 | DGM |
| 5 | MAT5-TX-5-140-FY09 | 15,106 | 38,549 | 1,972,125 | 0.0195 | 0.2132 | DGM |
| Average | | 14,887 | 38,130 | 1,910,698 | 0.0200 | 0.2159 | - |

Test Description:

The In-Plane Tensile Test per ASTM D3039 measures the in-plane tensile strength, elastic modulus and the in-plane Poisson's ratio of fiber reinforced polymer matrix composite materials. For this material, fibers are oriented in two dimensions, zero and ninety degree, within the glass laminates. For this test, load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (3T and 4T) are placed on adjacent sides of the specimen.

140°F Temperature Test Condition**Notes:**

- 1) 6 specimens tested, group of 5 displayed with relevant data shown
- 2) DGM corresponds with D=edge delamination, G=gauge area, M=middle of specimen
- 3) See H-14 to H-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 20-50% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-1-70-FY09**
 Test Date: 9/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 14,874 lbs
 Tensile Strength, ST_x : 38,133 psi
 Tensile Modulus, E_x : 1,939,161 psi
 Ultimate Strain, ϵ_x : 0.0197 in/in
 Poisson's Ratio, v_{xy} : 0.2744

Measured Specimen Dimensions:

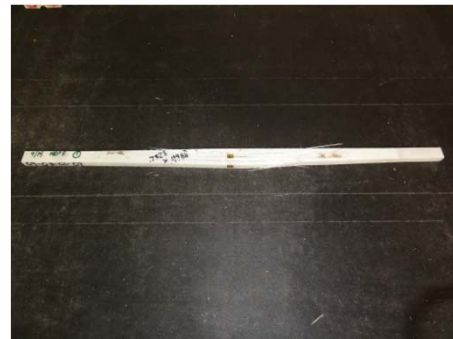
Width, W: 0.5004 in
 Thickness, H: 0.7795 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,975 lbs
 50% Max Load: 7,437 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

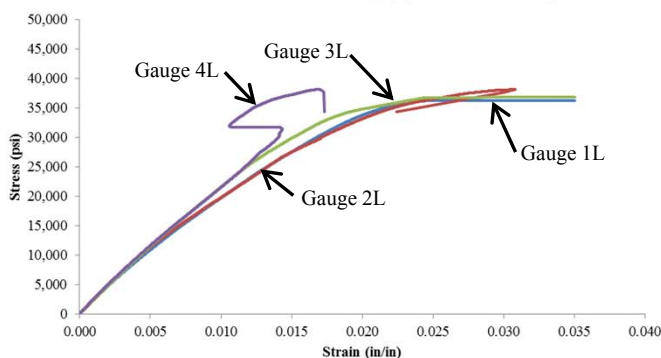


PICTURE OF SPECIMEN POST-TEST

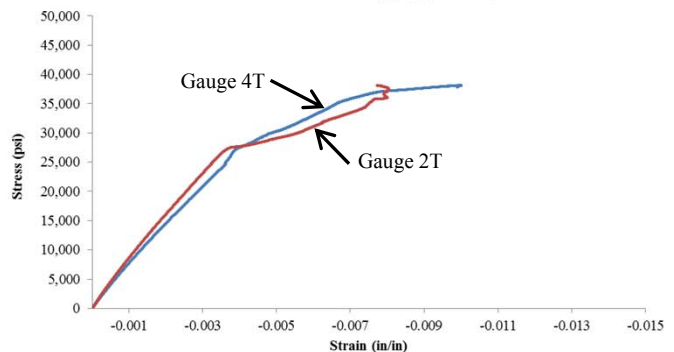


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0096 | 0.0033 | 1,829,147 | | | | |
| 2L | 0.0095 | 0.0032 | 1,801,932 | 2T | -0.0027 | -0.0010 | 0.2729 |
| 3L | 0.0087 | 0.0032 | 2,088,115 | | | | |
| 4L | 0.0088 | 0.0031 | 2,037,449 | 4T | -0.0024 | -0.0009 | 0.2759 |
| Average | | | 1,939,161 | | | | 0.2744 |

Stress-Strain Curve 140_1_(09-05), Long.



Stress-Strain Curve 140_1_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-2-70-FY09**
 Test Date: 9/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 15,226 lbs
 Tensile Strength, ST_x : 39,035 psi
 Tensile Modulus, E_x : 1,945,621 psi
 Ultimate Strain, ϵ_x : 0.0201 in/in
 Poisson's Ratio, v_{xy} : 0.1820

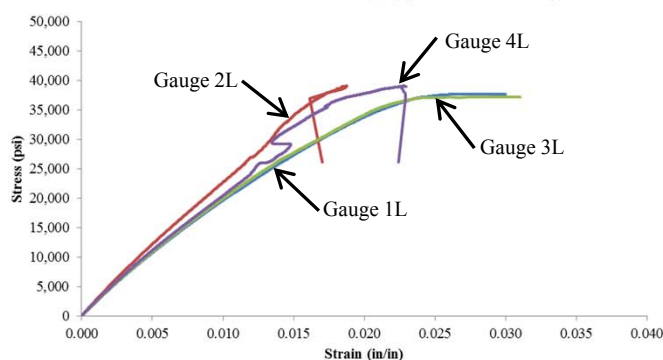
Measured Specimen Dimensions:

Width, W: 0.5004 in
 Thickness, H: 0.7795 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,045 lbs
 50% Max Load: 7,613 lbs

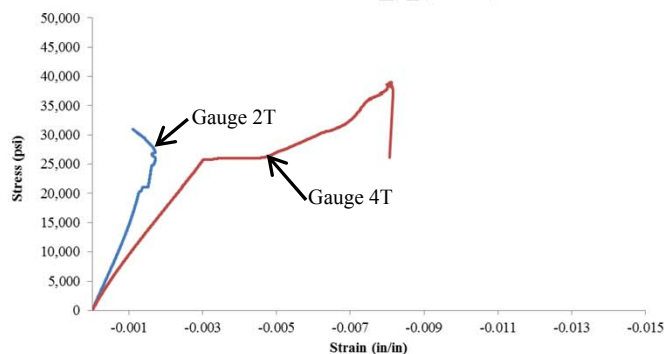
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0099 | 0.0035 | 1,827,292 | | | | |
| 2L | 0.0085 | 0.0031 | 2,175,730 | 2T | -0.0012 | -0.0006 | 0.1271 |
| 3L | 0.0097 | 0.0035 | 1,865,361 | | | | |
| 4L | 0.0095 | 0.0034 | 1,914,100 | 4T | -0.0022 | -0.0008 | 0.2370 |
| Average | | | 1,945,621 | | | | 0.1820 |

Stress-Strain Curve 140_2_(09-05), Long.



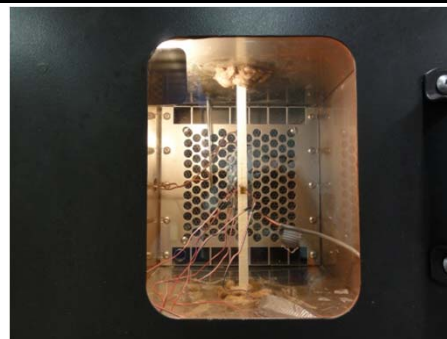
Stress-Strain Curve 140_2_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-3-70-FY09**
 Test Date: 9/15/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 15,180 lbs
 Tensile Strength, ST_x : 38,917 psi
 Tensile Modulus, E_x : 1,873,748 psi
 Ultimate Strain, ϵ_x : 0.0208 in/in
 Poisson's Ratio, v_{xy} : 0.1773

Measured Specimen Dimensions:

Width, W : 0.5004 in
 Thickness, H : 0.7795 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,036 lbs
 50% Max Load: 7,590 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

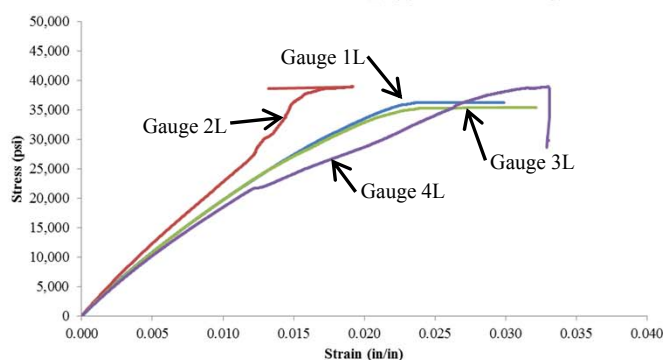


PICTURE OF SPECIMEN POST-TEST

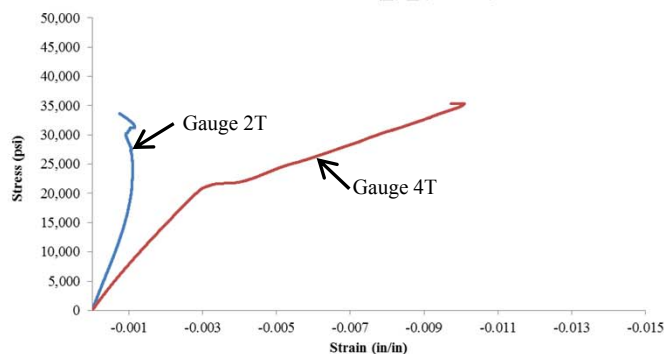


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0099 | 0.0034 | 1,819,701 | | | | |
| 2L | 0.0084 | 0.0030 | 2,166,954 | 2T | -0.0010 | -0.0005 | 0.1036 |
| 3L | 0.0099 | 0.0035 | 1,833,719 | | | | |
| 4L | 0.0107 | 0.0037 | 1,674,618 | 4T | -0.0027 | -0.0010 | 0.2510 |
| Average | | | 1,873,748 | | | | 0.1773 |

Stress-Strain Curve 140_3_(09-05), Long.



Stress-Strain Curve 140_3_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-4-70-FY09**
 Test Date: 9/15/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 14,048 lbs
 Tensile Strength, ST_x : 36,015 psi
 Tensile Modulus, E_x : 1,822,834 psi
 Ultimate Strain, ϵ_x : 0.0198 in/in
 Poisson's Ratio, v_{xy} : 0.2325

Measured Specimen Dimensions:

Width, W : 0.5004 in
 Thickness, H : 0.7795 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 2,810 lbs
 50% Max Load: 7,024 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

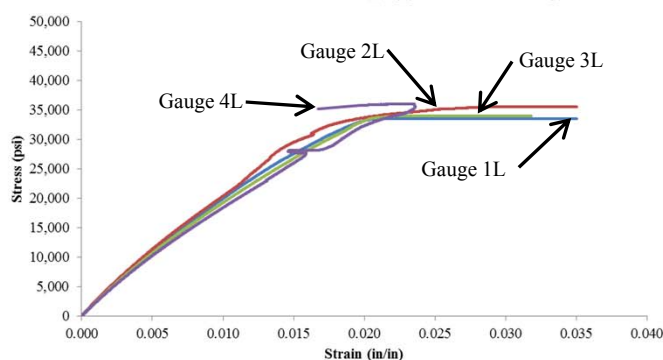


PICTURE OF SPECIMEN POST-TEST

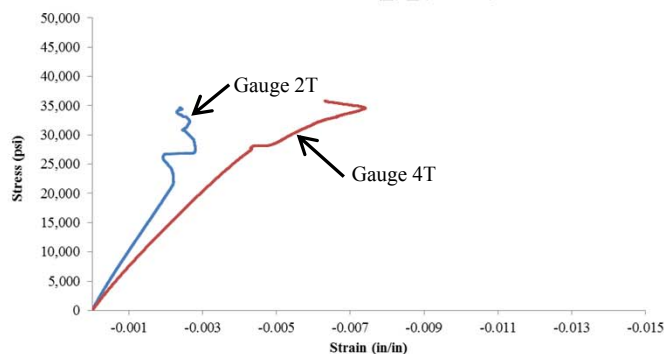


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0089 | 0.0031 | 1,879,861 | | | | |
| 2L | 0.0086 | 0.0030 | 1,922,391 | 2T | -0.0018 | -0.0007 | 0.2052 |
| 3L | 0.0092 | 0.0032 | 1,796,942 | | | | |
| 4L | 0.0097 | 0.0034 | 1,692,142 | 4T | -0.0026 | -0.0009 | 0.2598 |
| Average | | | 1,822,834 | | | | 0.2325 |

Stress-Strain Curve 140_4_(09-05), Long.



Stress-Strain Curve 140_4_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT5-TX-5-70-FY09**
 Test Date: 9/20/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

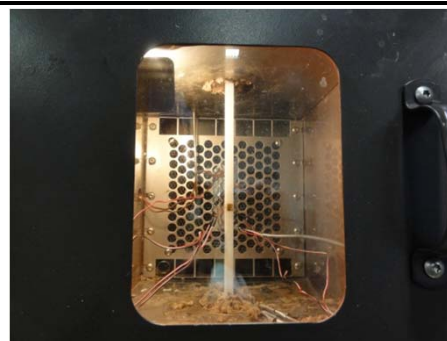
Ultimate Load, P_x : 15,106 lbs
 Tensile Strength, ST_x : 38,549 psi
 Tensile Modulus, E_x : 1,972,125 psi
 Ultimate Strain, ϵ_x : 0.0195 in/in
 Poisson's Ratio, v_{xy} : 0.2132

Measured Specimen Dimensions:

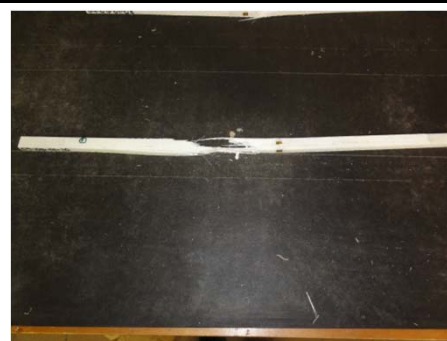
Width, W: 0.4950 in
 Thickness, H: 0.7917 in
 Laboratory Temperature: 68°F
 Failure Mode: DGM
 20% Max Load: 3,021 lbs
 50% Max Load: 7,553 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

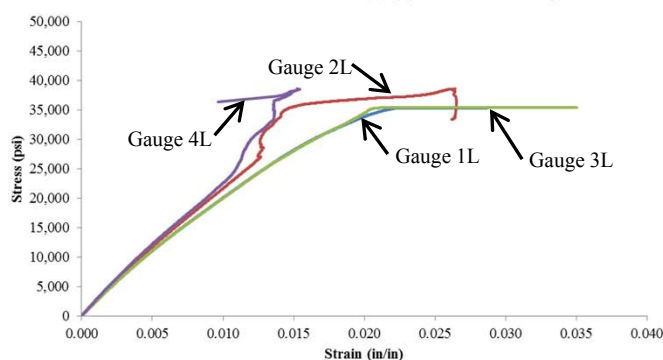


PICTURE OF SPECIMEN POST-TEST

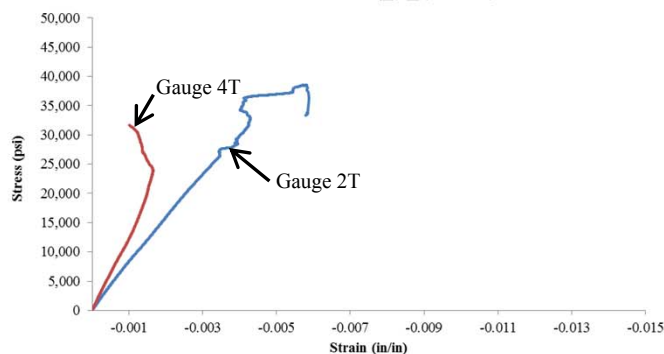


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0095 | 0.0033 | 1,859,889 | | | | |
| 2L | 0.0088 | 0.0031 | 2,047,074 | 2T | -0.0024 | -0.0009 | 0.2700 |
| 3L | 0.0096 | 0.0034 | 1,861,521 | | | | |
| 4L | 0.0085 | 0.0030 | 2,120,014 | 4T | -0.0015 | -0.0006 | 0.1564 |
| Average | | | 1,972,125 | | | | 0.2132 |

Stress-Strain Curve 140_5_(09-05), Long.



Stress-Strain Curve 140_5_(09-05), Lat.



Engineering Test notes:

- *The failure is classified as DGM for edge delamination originating in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-CX-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 35,969 lbs

Compressive Strength, SC_x : 45,159 psi

Compressive Modulus, E_x : 2,997,734 psi

Ultimate Strain, ϵ_x : 0.015 in/in

Poisson's Ratio, ν_{xy} : 0.261

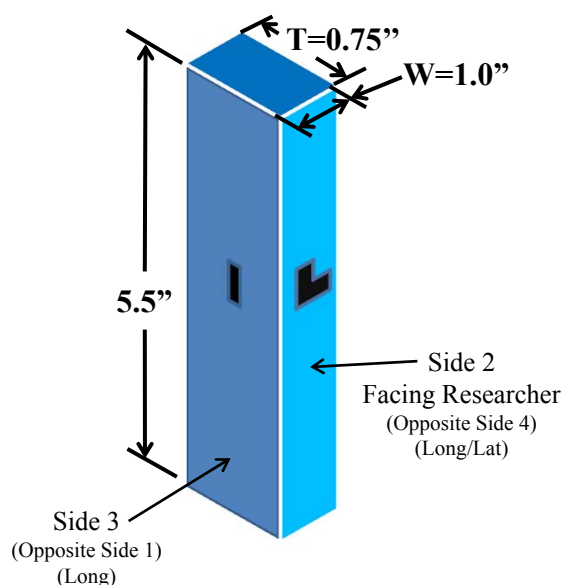
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT5-CX-01-N40-FY09 | 35,415 | 44,219 | 2,849,903 | 0.016 | 0.262 | Delamination |
| MAT5-CX-02-N40-FY09 | 35,281 | 44,250 | 2,993,030 | 0.015 | 0.228 | Delamination |
| MAT5-CX-03-N40-FY09 | 37,167 | 46,739 | 3,102,359 | 0.015 | 0.309 | Delamination |
| MAT5-CX-04-N40-FY09 | 35,022 | 44,114 | 3,062,479 | 0.014 | 0.272 | Delamination |
| MAT5-CX-05-N40-FY09 | 36,961 | 46,474 | 2,980,899 | 0.016 | 0.234 | Delamination |
| Average | 35,969 | 45,159 | 2,997,734 | 0.015 | 0.261 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See H-20 to H-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-01-N40-FY09**
 Test Date: 9/22/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 35,415 lbs
 Compressive Strength, SC_x : 44,219 psi
 Compressive Modulus, E_x : 2,849,903 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson's Ratio, ν_{xy} : 0.262

Measured Specimen Dimensions:

Width, W: 1.0032 in
 Thickness, H: 0.7983 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,083 lbs
 50% Max Load: 17,708 lbs

PICTURE OF SPECIMEN PRE-TEST



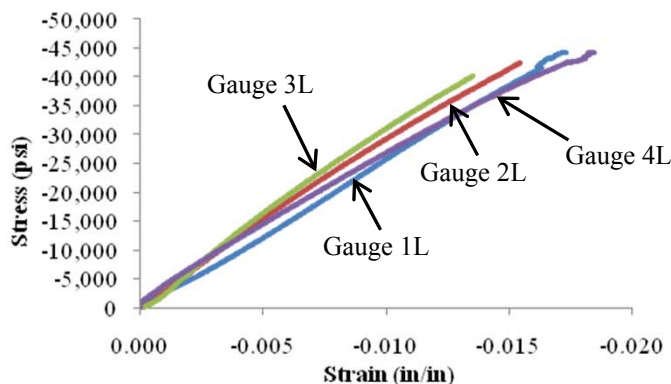
PICTURE OF SPECIMEN POST-TEST



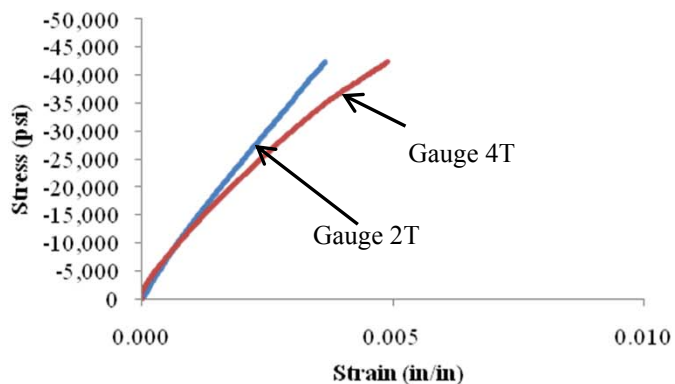
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00868 | -0.00372 | 2,673,082 | | | | |
| 2L | -0.00731 | -0.00287 | 2,985,634 | 2T | 0.00176 | 0.00062 | 0.256 |
| 3L | -0.00686 | -0.00274 | 3,215,703 | | | | |
| 4L | -0.00803 | -0.00278 | 2,525,194 | 4T | 0.00203 | 0.00062 | 0.267 |
| Average | | | 2,849,903 | | | | 0.262 |

Stress-Strain Curve N40_01_(09-05)_Long



Stress-Strain Curve N40_01_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-02-N40-FY09**
 Test Date: 9/22/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 35,281 lbs
 Compressive Strength, SC_x : 44,250 psi
 Compressive Modulus, E_x : 2,993,030 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.228

Measured Specimen Dimensions:

Width, W: 1.0080 in
 Thickness, H: 0.7910 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,056 lbs
 50% Max Load: 17,640 lbs

PICTURE OF SPECIMEN PRE-TEST



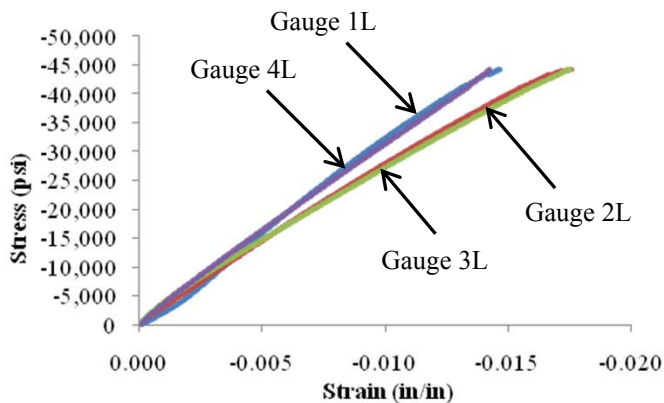
PICTURE OF SPECIMEN POST-TEST



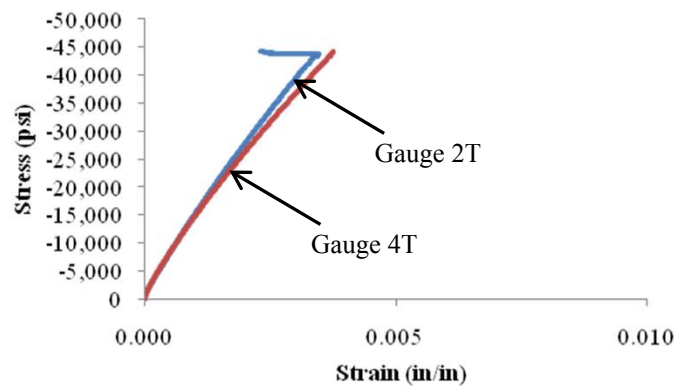
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00680 | -0.00309 | 3,580,559 | | | | |
| 2L | -0.00776 | -0.00297 | 2,773,404 | 2T | 0.00153 | 0.00054 | 0.206 |
| 3L | -0.00793 | -0.00272 | 2,546,314 | | | | |
| 4L | -0.00688 | -0.00256 | 3,071,845 | 4T | 0.00162 | 0.00053 | 0.350 |
| Average | | | 2,993,030 | | | | 0.228 |

Stress-Strain Curve N40_02_(09-05)_Long



Stress-Strain Curve N40_02_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-03-N40-FY09**
 Test Date: 9/23/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 37,167 lbs
 Compressive Strength, SC_x : 46,739 psi
 Compressive Modulus, E_x : 3,102,359 psi
 Ultimate Strain, ϵ_x : 0.015 in/in
 Poisson's Ratio, ν_{xy} : 0.309

Measured Specimen Dimensions:

Width, W: 1.0080 in
 Thickness, H: 0.7889 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,433 lbs
 50% Max Load: 18,584 lbs

PICTURE OF SPECIMEN PRE-TEST



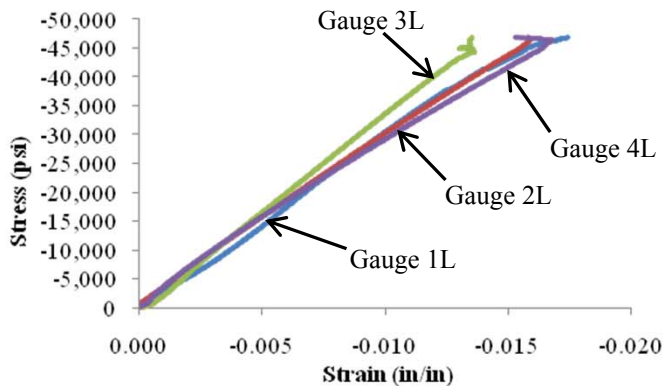
PICTURE OF SPECIMEN POST-TEST



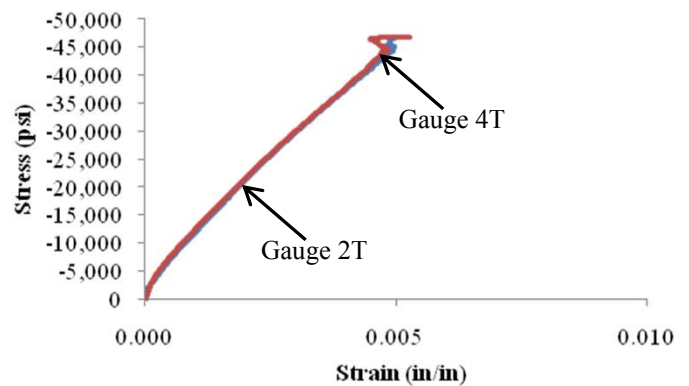
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00775 | -0.00348 | 3,277,730 | | | | |
| 2L | -0.00758 | -0.00279 | 2,924,992 | 2T | 0.00224 | 0.00073 | 0.314 |
| 3L | -0.00701 | -0.00290 | 3,414,000 | | | | |
| 4L | -0.00778 | -0.00276 | 2,792,712 | 4T | 0.00221 | 0.00068 | 0.304 |
| Average | | | 3,102,359 | | | | 0.309 |

Stress-Strain Curve N40_03_(09-05)_Long



Stress-Strain Curve N40_03_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-04-N40-FY09**
 Test Date: 9/23/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 35,022 lbs
 Compressive Strength, SC_x : 44,114 psi
 Compressive Modulus, E_x : 3,062,479 psi
 Ultimate Strain, ϵ_x : 0.014 in/in
 Poisson's Ratio, ν_{xy} : 0.272

Measured Specimen Dimensions:

Width, W: 1.0051 in
 Thickness, H: 0.7899 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,004 lbs
 50% Max Load: 17,511 lbs

PICTURE OF SPECIMEN PRE-TEST



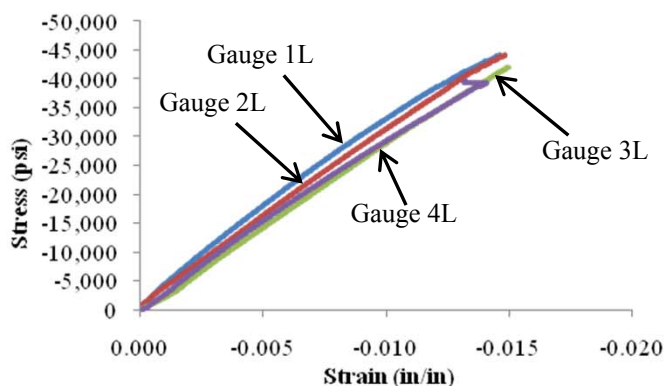
PICTURE OF SPECIMEN POST-TEST



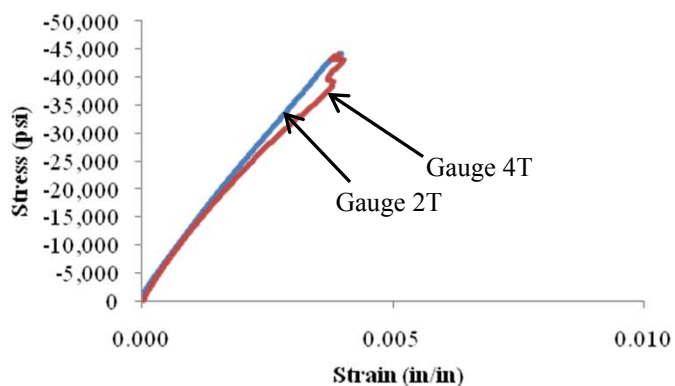
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00625 | -0.00221 | 3,275,826 | | | | |
| 2L | -0.00684 | -0.00257 | 3,097,550 | 2T | 0.00176 | 0.00061 | 0.268 |
| 3L | -0.00767 | -0.00317 | 2,938,861 | | | | |
| 4L | -0.00734 | -0.00283 | 2,937,676 | 4T | 0.00189 | 0.00065 | 0.276 |
| Average | | | 3,062,479 | | | | 0.272 |

Stress-Strain Curve N40_04_(09-05)_Long



Stress-Strain Curve N40_04_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-05-N40-FY09**
 Test Date: 9/23/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 36,961 lbs
 Compressive Strength, SC_x : 46,474 psi
 Compressive Modulus, E_x : 2,980,899 psi
 Ultimate Strain, ϵ_x : 0.016 in/in
 Poisson's Ratio, ν_{xy} : 0.234

Measured Specimen Dimensions:

Width, W: 1.0078 in
 Thickness, H: 0.7891 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,392 lbs
 50% Max Load: 18,480 lbs

PICTURE OF SPECIMEN PRE-TEST



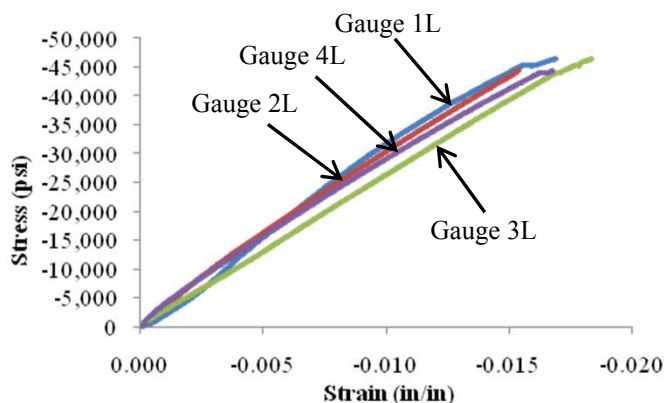
PICTURE OF SPECIMEN POST-TEST



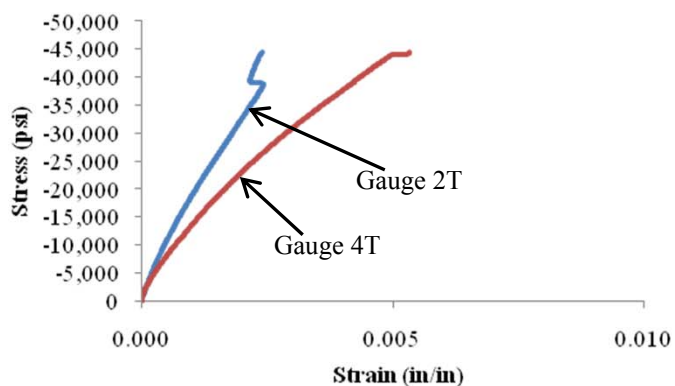
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00724 | -0.00330 | 3,334,236 | | | | |
| 2L | -0.00742 | -0.00268 | 3,200,506 | 2T | 0.00130 | 0.00041 | 0.188 |
| 3L | -0.00881 | -0.00357 | 3,412,745 | | | | |
| 4L | -0.00776 | -0.00274 | 2,829,451 | 4T | 0.00201 | 0.00060 | 0.281 |
| Average | | | 3,194,234 | | | | 0.234 |

Stress-Strain Curve N40_05_(09-05)_Long



Stress-Strain Curve N40_05_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-CX-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 26,442 lbs

Compressive Strength, SC_x : 32,687 psi

Compressive Modulus, E_x : 2,890,905 psi

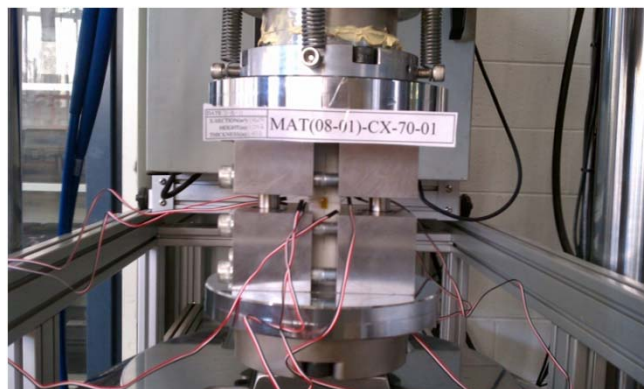
Ultimate Strain, ϵ_x : 0.011 in/in

Poisson's Ratio, ν_{xy} : 0.256

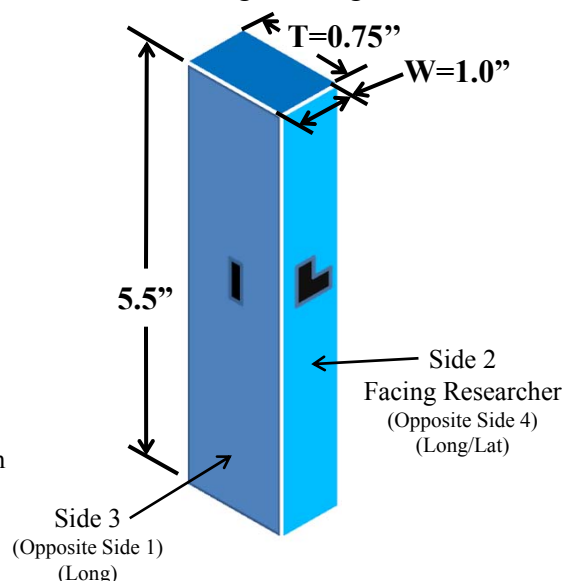
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT5-CX-01-70-FY09 | 26,515 | 32,423 | 3,010,883 | 0.011 | 0.249 | Delamination |
| MAT5-CX-02-70-FY09 | 27,417 | 34,063 | 2,939,381 | 0.012 | 0.251 | Delamination |
| MAT5-CX-03-70-FY09 | 26,909 | 33,456 | 2,948,815 | 0.011 | 0.252 | Delamination |
| MAT5-CX-04-70-FY09 | 26,686 | 32,824 | 2,796,515 | 0.012 | 0.264 | Delamination |
| MAT5-CX-05-70-FY09 | 24,684 | 30,671 | 2,758,931 | 0.011 | 0.262 | Delamination |
| Average | 26,442 | 32,687 | 2,890,905 | 0.011 | 0.256 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See H-26 to H-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-01-70-FY09**
 Test Date: 10/6/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 26,515 lbs
 Compressive Strength, SC_x : 32,423 psi
 Compressive Modulus, E_x : 3,010,883 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, v_{xy} : 0.249

Measured Specimen Dimensions:

Width, W: 1.022 in
 Thickness, H: 0.8000 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,303 lbs
 50% Max Load: 13,258 lbs

PICTURE OF SPECIMEN PRE-TEST



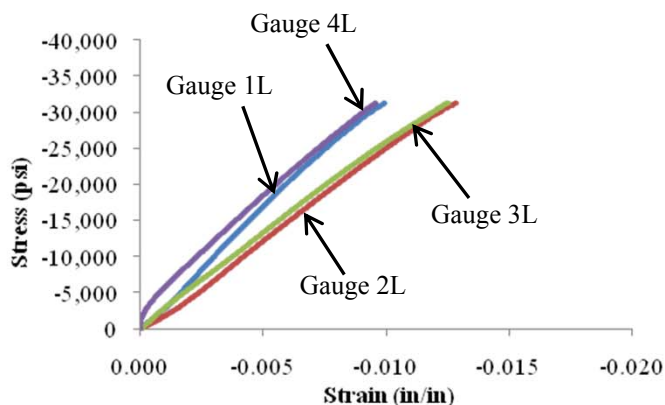
PICTURE OF SPECIMEN POST-TEST



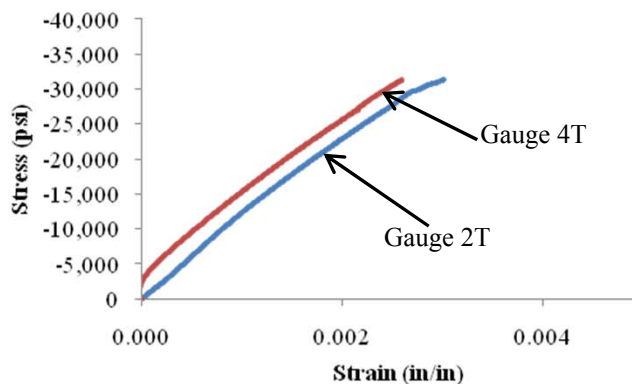
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00477 | -0.00203 | 3,555,548 | | | | |
| 2L | -0.00652 | -0.00292 | 2,704,372 | 2T | 0.00134 | 0.00053 | 0.228 |
| 3L | -0.00607 | -0.00235 | 2,613,302 | | | | |
| 4L | -0.00426 | -0.00119 | 3,170,311 | 4T | 0.00108 | 0.00025 | 0.271 |
| Average | | | 3,010,883 | | | | 0.249 |

Stress-Strain Curve 70F_01_(09-05)_Long



Stress-Strain Curve 70F_01_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-02-70-FY09**
 Test Date: 10/6/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 27,417 lbs
 Compressive Strength, SC_x : 34,063 psi
 Compressive Modulus, E_x : 2,939,381 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.251

Measured Specimen Dimensions:

Width, W: 1.0044 in
 Thickness, H: 0.8049 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,483 lbs
 50% Max Load: 13,709 lbs

PICTURE OF SPECIMEN PRE-TEST



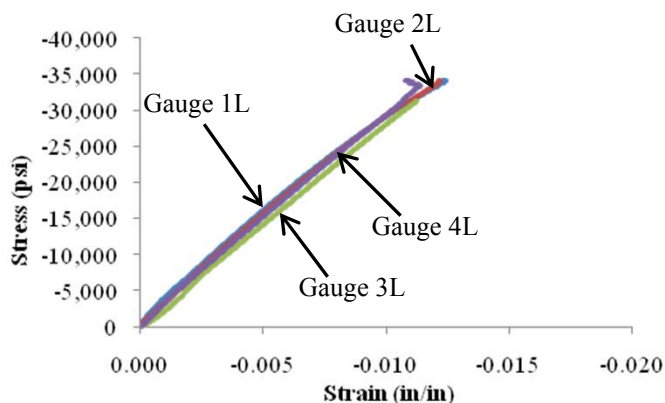
PICTURE OF SPECIMEN POST-TEST



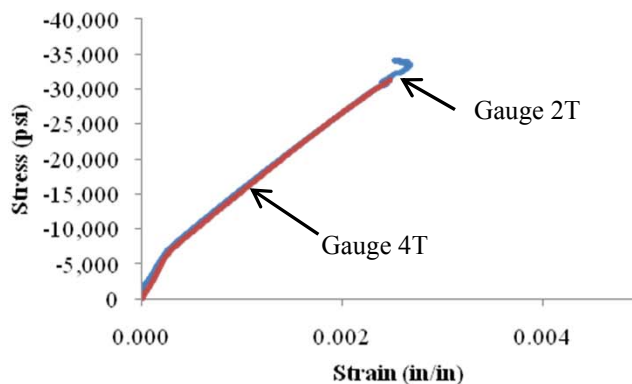
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00530 | -0.00192 | 3,019,628 | | | | |
| 2L | -0.00546 | -0.00206 | 3,006,716 | 2T | 0.00111 | 0.00024 | 0.255 |
| 3L | -0.00602 | -0.00238 | 2,805,769 | | | | |
| 4L | -0.00561 | -0.00212 | 2,925,412 | 4T | 0.00114 | 0.00028 | 0.247 |
| Average | | | 2,939,381 | | | | 0.251 |

Stress-Strain Curve 70F_02_(09-05)_Long



Stress-Strain Curve 70F_02_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-03-70-FY09**
 Test Date: 10/14/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 26,909 lbs
 Compressive Strength, SC_x : 33,456 psi
 Compressive Modulus, E_x : 2,948,815 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, v_{xy} : 0.252

Measured Specimen Dimensions:

Width, W: 1.0182 in
 Thickness, H: 0.7899 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,382 lbs
 50% Max Load: 13,454 lbs

PICTURE OF SPECIMEN PRE-TEST



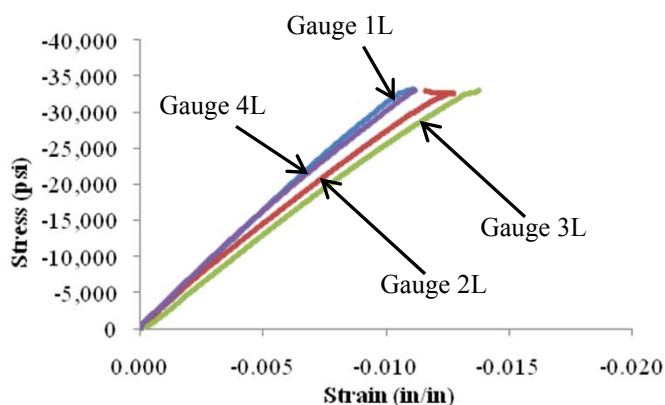
PICTURE OF SPECIMEN POST-TEST



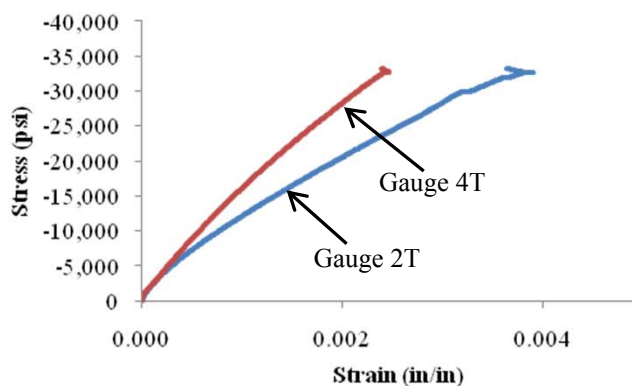
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00508 | -0.00203 | 3,288,862 | | | | |
| 2L | -0.00581 | -0.00211 | 2,708,475 | 2T | 0.00153 | 0.00044 | 0.293 |
| 3L | -0.00640 | -0.00264 | 3,105,363 | | | | |
| 4L | -0.00512 | -0.00191 | 3,128,703 | 4T | 0.00104 | 0.00036 | 0.221 |
| Average | | | 2,948,815 | | | | 0.252 |

Stress-Strain Curve 70F_03_(09-05)_Long



Stress-Strain Curve 70F_03_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-04-70-FY09**
 Test Date: 10/14/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 26,686 lbs
 Compressive Strength, SC_x : 32,824 psi
 Compressive Modulus, E_x : 2,796,515 psi
 Ultimate Strain, ϵ_x : 0.012 in/in
 Poisson's Ratio, ν_{xy} : 0.264

Measured Specimen Dimensions:

Width, W: 1.0195 in
 Thickness, H: 0.8130 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 5,337 lbs
 50% Max Load: 13,343 lbs

PICTURE OF SPECIMEN PRE-TEST



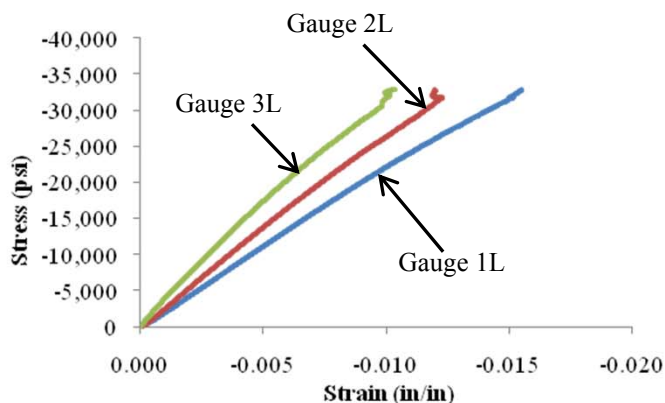
PICTURE OF SPECIMEN POST-TEST



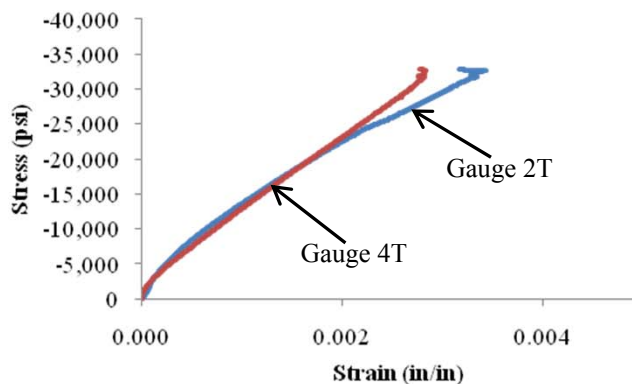
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00733 | -0.00300 | 2,277,693 | | | | |
| 2L | -0.00598 | -0.00241 | 2,757,329 | 2T | 0.00129 | 0.00035 | 0.264 |
| 3L | -0.00468 | -0.00174 | 3,354,523 | | | | |
| 4L | Lost Gauge | Lost gauge | - | 4T | 0.00133 | 0.00041 | N/A |
| Average | | | 2,796,515 | | | | 0.264 |

Stress-Strain Curve 70F_04_(09-05)_Long



Stress-Strain Curve 70F_04_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-05-70-FY09**
 Test Date: 10/14/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 24,684 lbs
 Compressive Strength, SC_x : 30,671 psi
 Compressive Modulus, E_x : 2,758,931 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.262

Measured Specimen Dimensions:

Width, W: 1.0060 in
 Thickness, H: 0.8000 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,937 lbs
 50% Max Load: 12,342 lbs

PICTURE OF SPECIMEN PRE-TEST



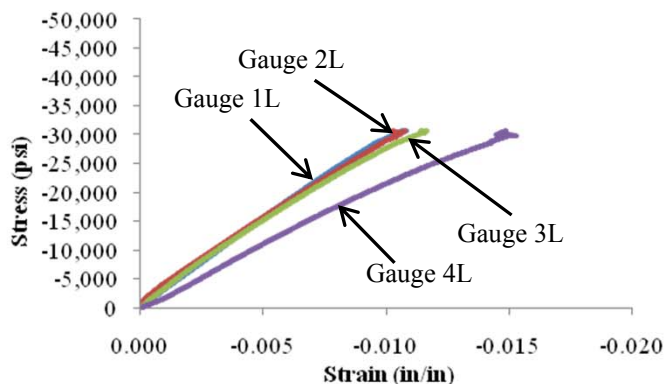
PICTURE OF SPECIMEN POST-TEST



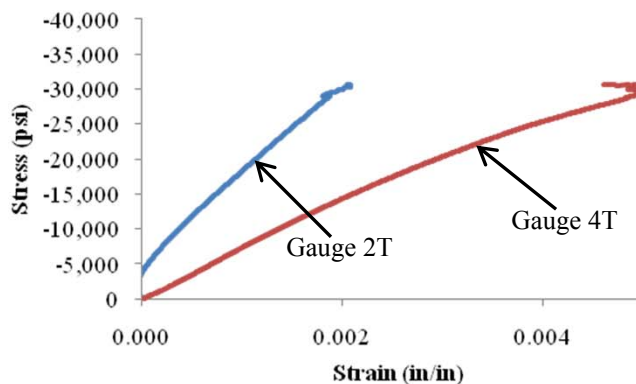
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00491 | -0.00192 | 3,082,943 | | | | |
| 2L | -0.00486 | -0.00162 | 2,832,928 | 2T | 0.00077 | 0.00012 | 0.199 |
| 3L | -0.00506 | -0.00183 | 2,850,465 | | | | |
| 4L | -0.00694 | -0.00289 | 2,269,389 | 4T | 0.00215 | 0.00084 | 0.324 |
| Average | | | 2,758,931 | | | | 0.262 |

Stress-Strain Curve 70F_05_(09-05)_Long



Stress-Strain Curve 70F_05_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-CX-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 20,612 lbs

Compressive Strength, SC_x : 26,120 psi

Compressive Modulus, E_x : 2,662,344 psi

Ultimate Strain, ϵ_x : 0.010 in/in

Poisson's Ratio, ν_{xy} : 0.276

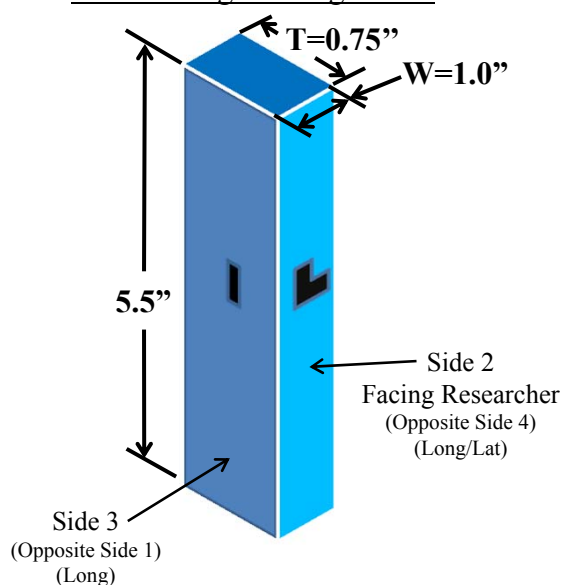
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT5-CX-01-140-FY09 | 22,442 | 27,621 | 2,764,732 | 0.010 | 0.298 | Delamination |
| MAT5-CX-02-140-FY09 | 20,319 | 26,110 | 2,819,048 | 0.009 | 0.263 | Delamination |
| MAT5 CX-03-140-FY09 | 21,265 | 27,642 | 2,557,567 | 0.011 | 0.240 | Delamination |
| MAT5-CX-04-140-FY09 | 21,070 | 26,844 | 2,617,283 | 0.010 | 0.312 | Delamination |
| MAT5-CX-05-140-FY09 | 17,962 | 22,383 | 2,553,091 | 0.009 | 0.269 | Delamination |
| Average | 20,612 | 26,120 | 2,662,344 | 0.010 | 0.276 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See H-32 to H-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-01-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 22,442 lbs
 Compressive Strength, SC_x : 27,621 psi
 Compressive Modulus, E_x : 2,764,732 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, v_{xy} : 0.298

Measured Specimen Dimensions:

Width, W: 1.0311 in
 Thickness, H: 0.7880 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,488 lbs
 50% Max Load: 11,221 lbs

PICTURE OF SPECIMEN PRE-TEST



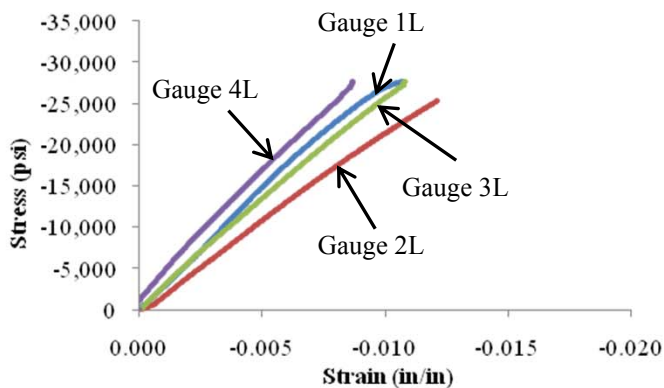
PICTURE OF SPECIMEN POST-TEST



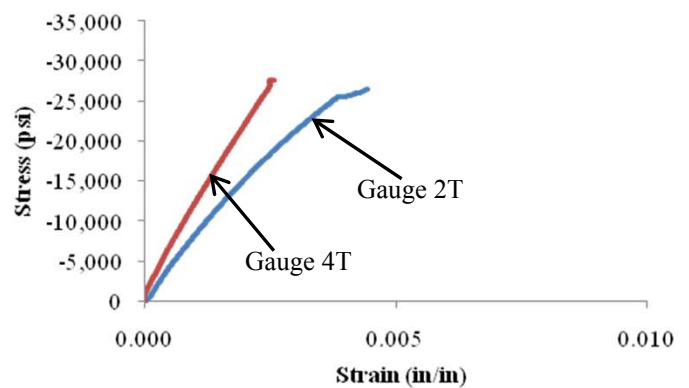
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00464 | -0.00196 | 3,096,853 | | | | |
| 2L | -0.00633 | -0.00268 | 2,267,229 | 2T | 0.00178 | 0.00065 | 0.308 |
| 3L | -0.00512 | -0.00191 | 2,587,445 | | | | |
| 4L | -0.00392 | -0.00125 | 3,107,401 | 4T | 0.00115 | 0.00038 | 0.287 |
| Average | | | 2,764,732 | | | | 0.298 |

Stress-Strain Curve 140F_01_(09-05)_Long



Stress-Strain Curve 140F_01_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-02-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 20,319 lbs
 Compressive Strength, SC_x : 26,110 psi
 Compressive Modulus, E_x : 2,819,048 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.263

Measured Specimen Dimensions:

Width, W: 0.9802 in
 Thickness, H: 0.7939 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,064 lbs
 50% Max Load: 10,160 lbs

PICTURE OF SPECIMEN PRE-TEST



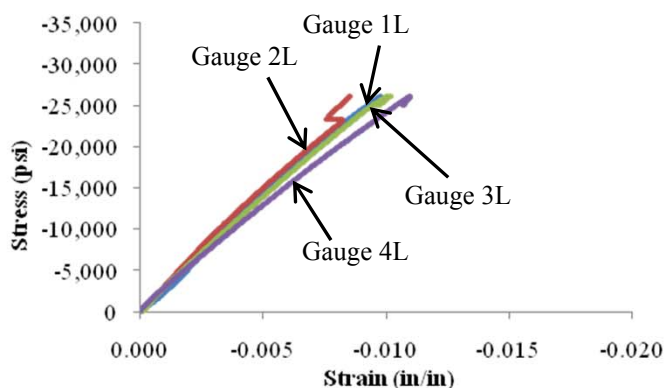
PICTURE OF SPECIMEN POST-TEST



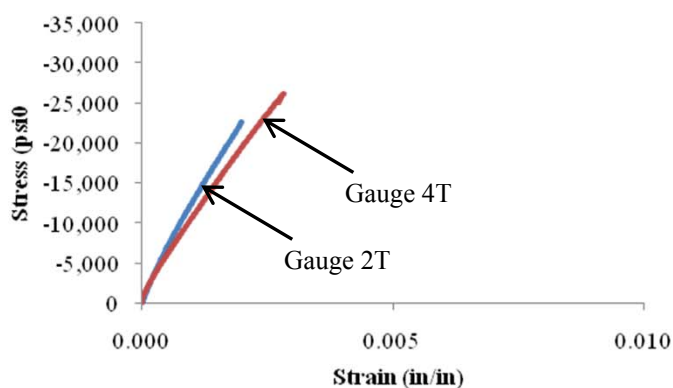
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00447 | -0.00196 | 3,124,735 | | | | |
| 2L | -0.00427 | -0.00162 | 2,963,666 | 2T | 0.00104 | 0.00036 | 0.259 |
| 3L | -0.00465 | -0.00177 | 2,722,307 | | | | |
| 4L | -0.00503 | -0.00185 | 2,465,485 | 4T | 0.00126 | 0.00041 | 0.267 |
| Average | | | 2,819,048 | | | | 0.263 |

Stress-Strain Curve 140F_02_(09-05)_Long



Stress-Strain Curve 140F_02_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-03-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 21,265 lbs
 Compressive Strength, SC_x : 27,642 psi
 Compressive Modulus, E_x : 2,557,567 psi
 Ultimate Strain, ϵ_x : 0.011 in/in
 Poisson's Ratio, ν_{xy} : 0.240

Measured Specimen Dimensions:

Width, W : 0.9713 in
 Thickness, H : 0.7920 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,253 lbs
 50% Max Load: 10,633 lbs

PICTURE OF SPECIMEN PRE-TEST



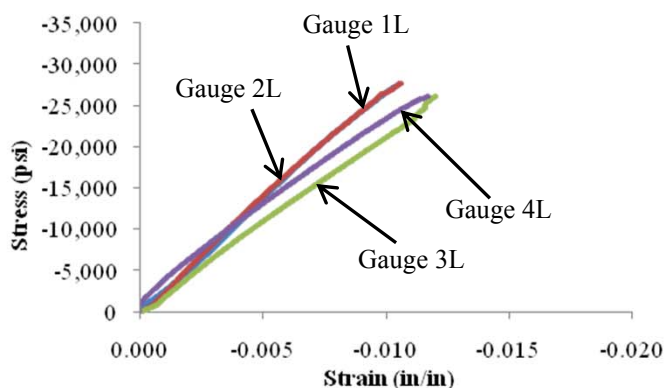
PICTURE OF SPECIMEN POST-TEST



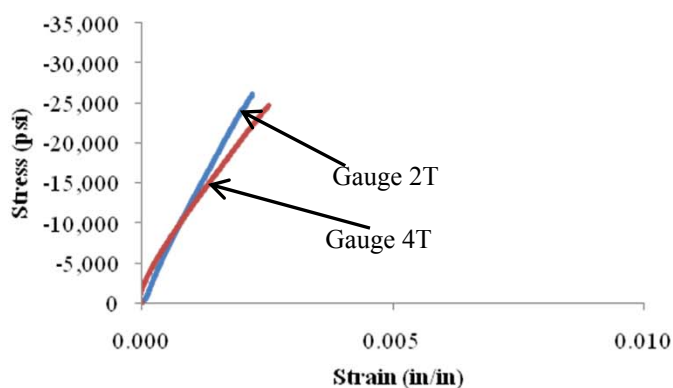
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00504 | -0.00219 | 2,909,576 | | | | |
| 2L | -0.00490 | -0.00205 | 2,904,024 | 2T | 0.00109 | 0.00041 | 0.236 |
| 3L | -0.00636 | -0.00253 | 2,165,619 | | | | |
| 4L | -0.00531 | -0.00163 | 2,251,048 | 4T | 0.00120 | 0.00030 | 0.244 |
| Average | | | 2,557,567 | | | | 0.240 |

Stress-Strain Curve 140F_03_(09-05)_Long



Stress-Strain Curve 140F_03_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-04-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 21,070 lbs
 Compressive Strength, SC_x : 26,844 psi
 Compressive Modulus, E_x : 2,617,283 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.312

Measured Specimen Dimensions:

Width, W: 0.9875 in
 Thickness, H: 0.7948 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,214 lbs
 50% Max Load: 10,535 lbs

PICTURE OF SPECIMEN PRE-TEST



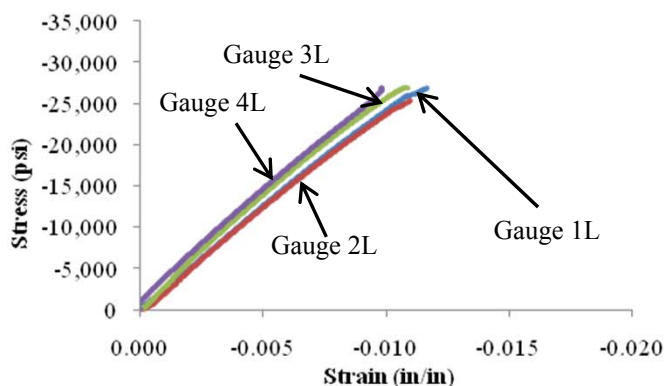
PICTURE OF SPECIMEN POST-TEST



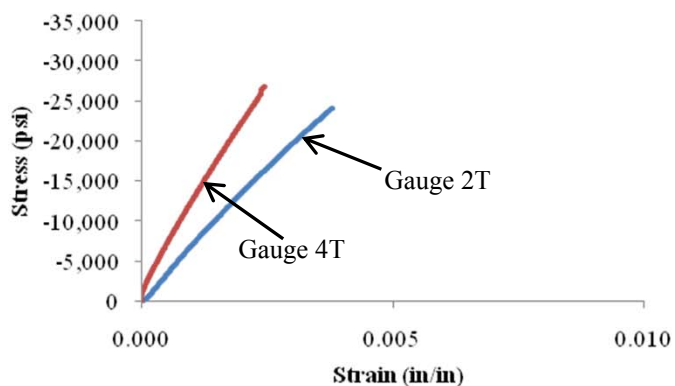
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00532 | -0.00215 | 2,617,283 | | | | |
| 2L | -0.00542 | -0.00222 | 2,518,924 | 2T | 0.00198 | 0.00077 | 0.378 |
| 3L | -0.00479 | -0.00183 | 2,721,489 | | | | |
| 4L | -0.00450 | -0.00151 | 2,685,225 | 4T | 0.00108 | 0.00034 | 0.247 |
| Average | | | 2,617,283 | | | | 0.312 |

Stress-Strain Curve 140F_04_(09-05)_Long



Stress-Strain Curve 140F_04_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT5-CX-05-140-FY09**
 Test Date: 9/27/2011
 Specimen Received: 8/31/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 17,962 lbs
 Compressive Strength, SC_x : 22,383 psi
 Compressive Modulus, E_x : 2,553,091 psi
 Ultimate Strain, ϵ_x : 0.009 in/in
 Poisson's Ratio, ν_{xy} : 0.269

Measured Specimen Dimensions:

Width, W: 1.0045 in
 Thickness, H: 0.7989 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 3,592 lbs
 50% Max Load: 8,981 lbs

PICTURE OF SPECIMEN PRE-TEST



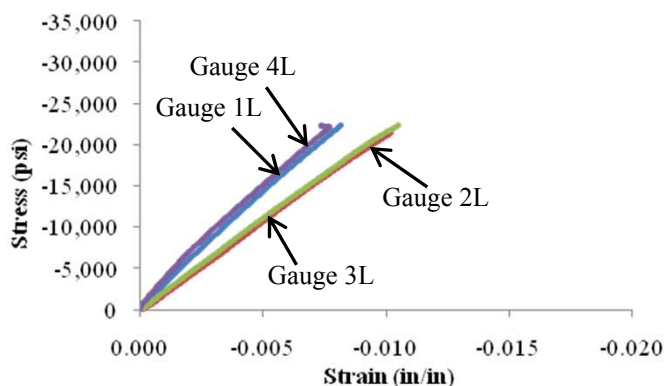
PICTURE OF SPECIMEN POST-TEST



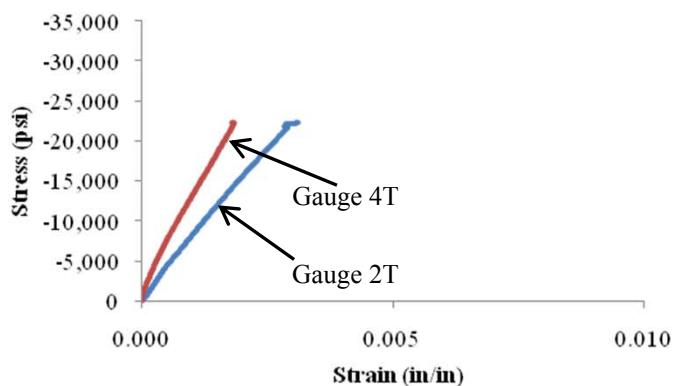
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00381 | -0.00143 | 2,823,915 | | | | |
| 2L | -0.00521 | -0.00219 | 2,229,496 | 2T | 0.00139 | 0.00050 | 0.293 |
| 3L | -0.00501 | -0.00200 | 2,232,189 | | | | |
| 4L | -0.00347 | -0.00118 | 2,926,765 | 4T | 0.00081 | 0.00025 | 0.245 |
| Average | | | 2,553,091 | | | | 0.269 |

Stress-Strain Curve 140F_05_(09-05)_Long



Stress-Strain Curve 140F_05_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXY-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 15,587 lbs

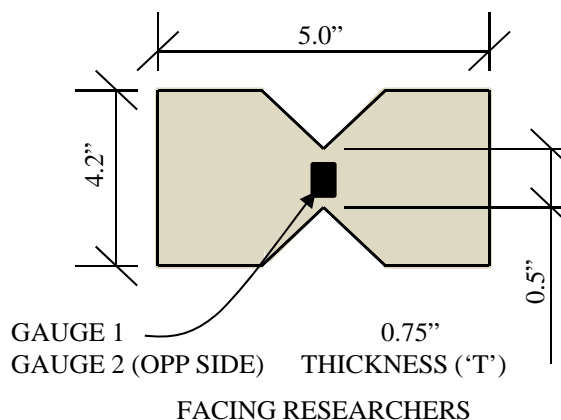
Shear Strength, S_{xy} : 36,915 psi

Shear Modulus, G_{xy} : 1,516,312 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT5-SXY-01-N40-FY09 | 15,589 | 37,746 | 1,570,433 | Shear |
| 2 | MAT5-SXY-02-N40-FY09 | 15,622 | 37,367 | 1,470,865 | Shear |
| 3 | MAT5-SXY-03-N40-FY09 | 14,890 | 33,931 | 1,473,467 | Shear |
| 4 | MAT5-SXY-04-N40-FY09 | 16,048 | 38,080 | 1,637,105 | Shear |
| 5 | MAT5-SXY-05-N40-FY09 | 15,789 | 37,452 | 1,429,692 | Shear |
| Average | | 15,587 | 36,915 | 1,516,312 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets H-38 to H-42
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-01-N40-FY09
 Test Date: 04/13/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

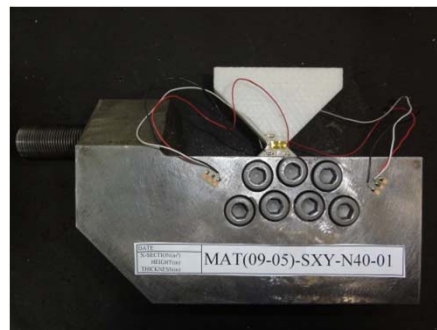
Average Material Properties:

Maximum Load, P_{max} : 15,589 lbs
 Shear Strength, S_{xy} : 37,746 psi
 Shear Modulus, G_{xy} : 1,570,433 psi

Measured Specimen Dimensions:

Thickness, T : 0.7388 in
 Notch Length, N : 0.5590 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,118 lbs
 50% Max Load: 7,794 lbs

PICTURE OF SPECIMEN PRE-TEST



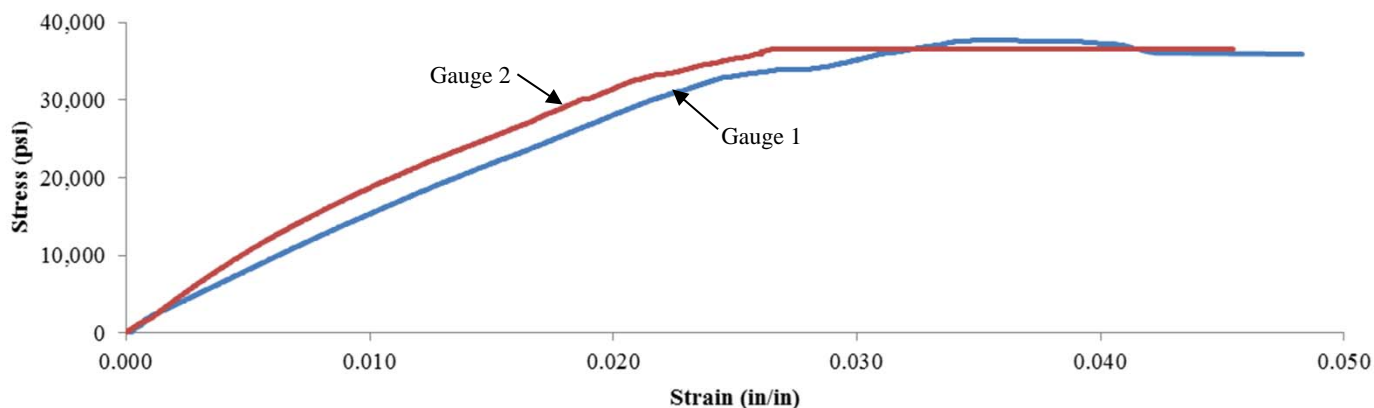
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01259 | 0.00460 | 1,417,200 |
| 2 | 0.01007 | 0.00350 | 1,723,666 |
| Average | | | 1,570,433 |

Stress-Strain Curve -40°F_1_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-02-N40-FY09
 Test Date: 04/18/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 15,622 lbs
 Shear Strength, S_{xy} : 37,367 psi
 Shear Modulus, G_{xy} : 1,470,865 psi

Measured Specimen Dimensions:

Thickness, T : 0.7492 in
 Notch Length, N : 0.5580 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,124 lbs
 50% Max Load: 7,811 lbs

PICTURE OF SPECIMEN PRE-TEST



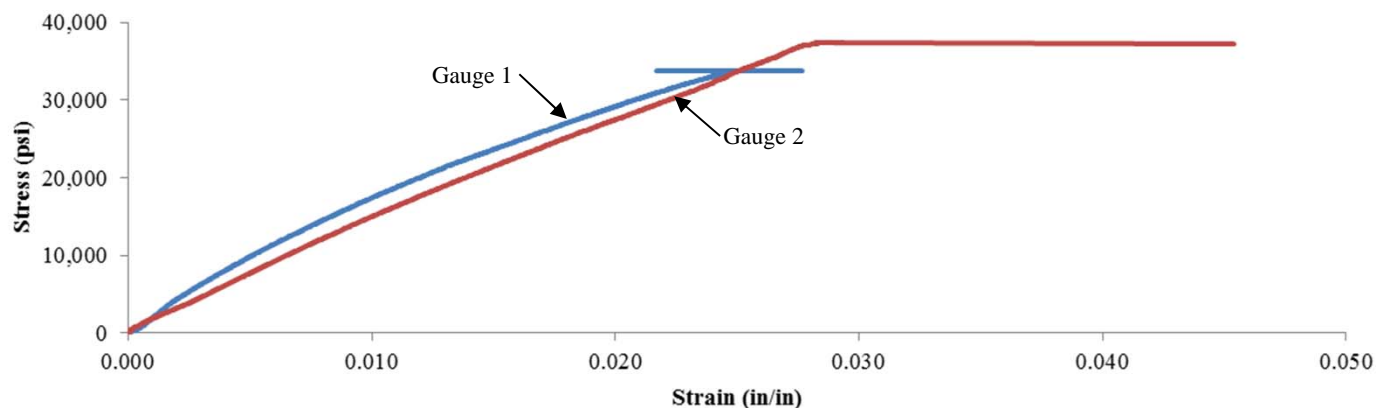
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01094 | 0.00363 | 1,532,770 |
| 2 | 0.01278 | 0.00483 | 1,408,961 |
| Average | | | 1,470,865 |

Stress-Strain Curve -40°F_2_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-03-N40-FY09
 Test Date: 04/19/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

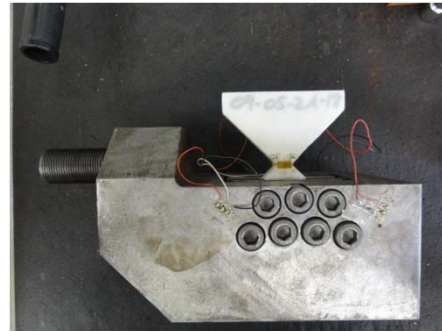
Average Material Properties:

Maximum Load, P_{max} : 14,890 lbs
 Shear Strength, S_{xy} : 33,931 psi
 Shear Modulus, G_{xy} : 1,473,467 psi

Measured Specimen Dimensions:

Thickness, T: 0.7553 in
 Notch Length, N: 0.5810 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,978 lbs
 50% Max Load: 7,445 lbs

PICTURE OF SPECIMEN PRE-TEST



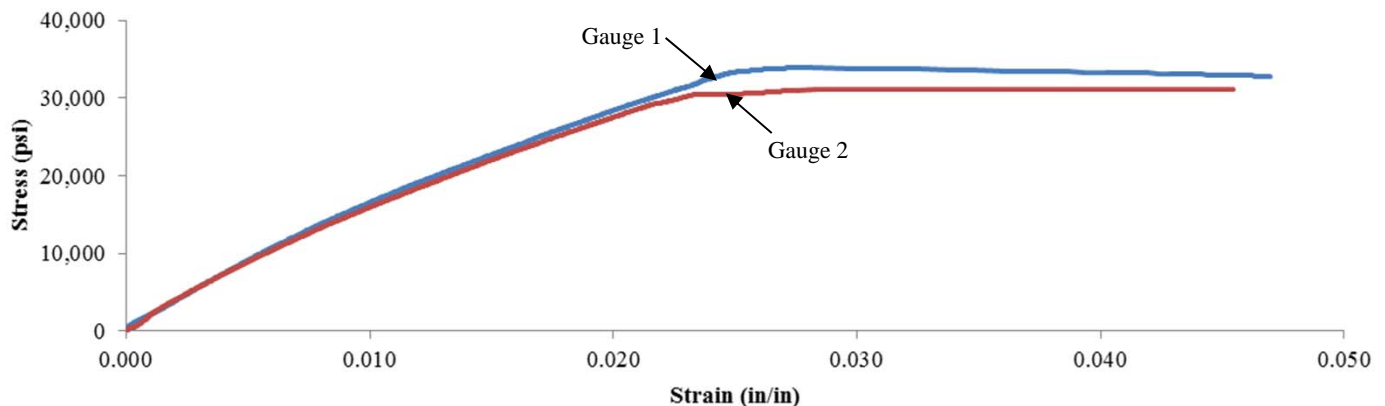
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01028 | 0.00361 | 1,525,905 |
| 2 | 0.01079 | 0.00363 | 1,421,029 |
| Average | | | 1,473,467 |

Stress-Strain Curve -40°F_3_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-04-N40-FY09
 Test Date: 04/27/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

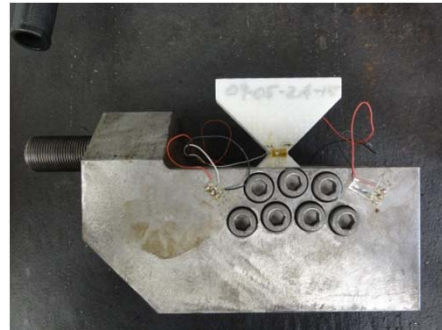
Average Material Properties:

Maximum Load, P_{max} : 16,048 lbs
 Shear Strength, S_{xy} : 38,080 psi
 Shear Modulus, G_{xy} : 1,637,105 psi

Measured Specimen Dimensions:

Thickness, T: 0.7607 in
 Notch Length, N: 0.5540 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,210 lbs
 50% Max Load: 8,024 lbs

PICTURE OF SPECIMEN PRE-TEST



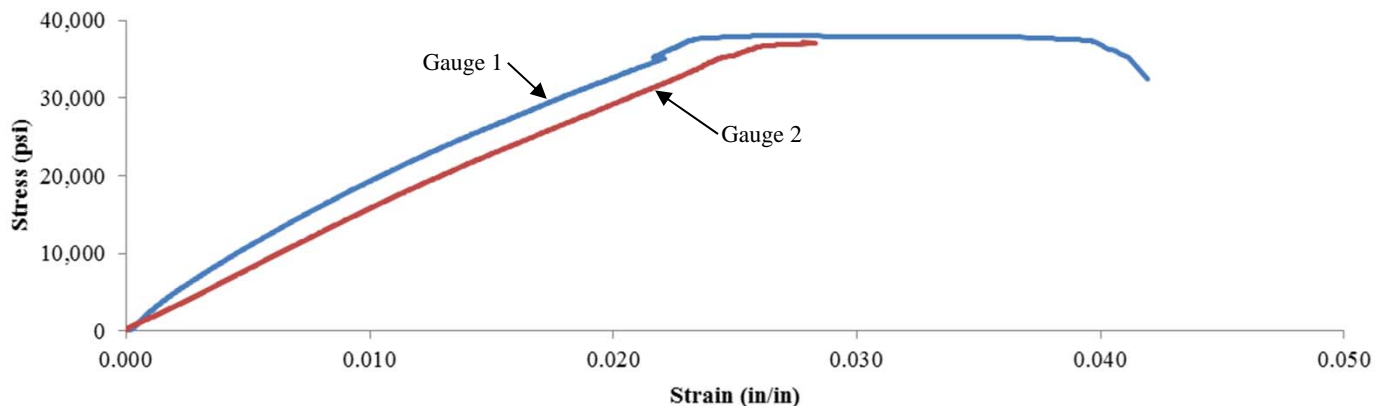
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00984 | 0.00328 | 1,742,908 |
| 2 | 0.01222 | 0.00476 | 1,531,301 |
| Average | | | 1,637,105 |

Stress-Strain Curve -40°F_4_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-05-N40-FY09
 Test Date: 05/2/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

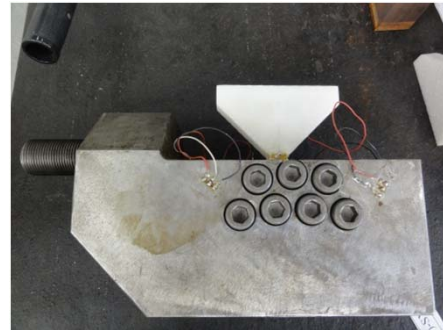
Average Material Properties:

Maximum Load, P_{max} : 15,789 lbs
 Shear Strength, S_{xy} : 37,452 psi
 Shear Modulus, G_{xy} : 1,429,692 psi

Measured Specimen Dimensions:

Thickness, T : 0.7610 in
 Notch Length, N : 0.5540 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 3,158 lbs
 50% Max Load: 7,895 lbs

PICTURE OF SPECIMEN PRE-TEST



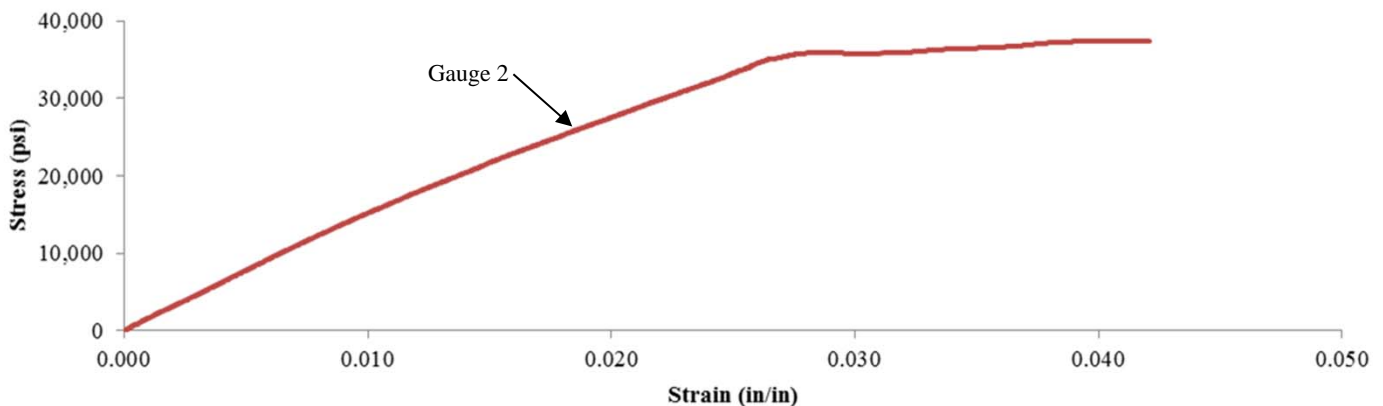
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | Lost Gauge | Lost Gauge | LG |
| 2 | 0.01265 | 0.00479 | 1,429,692 |
| Average | | | 1,429,692 |

Stress-Strain Curve -40°F_5_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXY-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 12,226 lbs

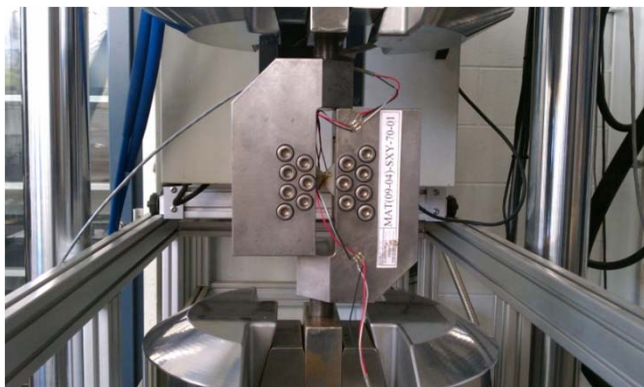
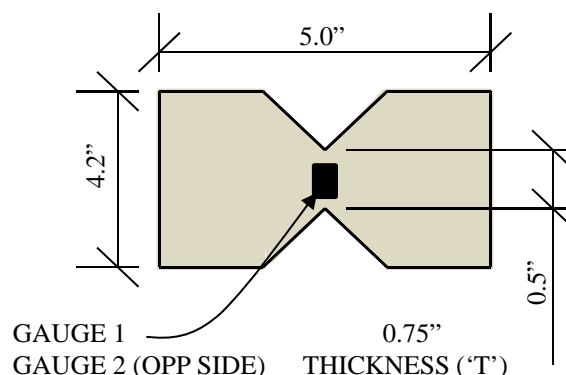
Shear Strength, S_{xy} : 28,755 psi

Shear Modulus, G_{xy} : 1,427,879 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT5-SXY-01-70-FY09 | 12,016 | 28,954 | 1,514,751 | Shear |
| 2 | MAT5-SXY-02-70-FY09 | 12,332 | 29,503 | 1,383,699 | Shear |
| 3 | MAT5-SXY-03-70-FY09 | 12,280 | 29,448 | 1,475,655 | Shear |
| 4 | MAT5-SXY-04-70-FY09 | 12,431 | 29,045 | 1,423,715 | Shear |
| 5 | MAT5-SXY-05-70-FY09 | 12,071 | 26,824 | 1,341,577 | Shear |
| Average | | 12,226 | 28,755 | 1,427,879 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets H-44 to H-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-01-70-FY09
 Test Date: 01/31/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,016 lbs
 Shear Strength, S_{xy} : 28,954 psi
 Shear Modulus, G_{xy} : 1,514,751 psi

Measured Specimen Dimensions:

Thickness, T: 0.7517 in
 Notch Length, N: 0.552 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,403 lbs
 50% Max Load: 6,008 lbs

PICTURE OF SPECIMEN PRE-TEST



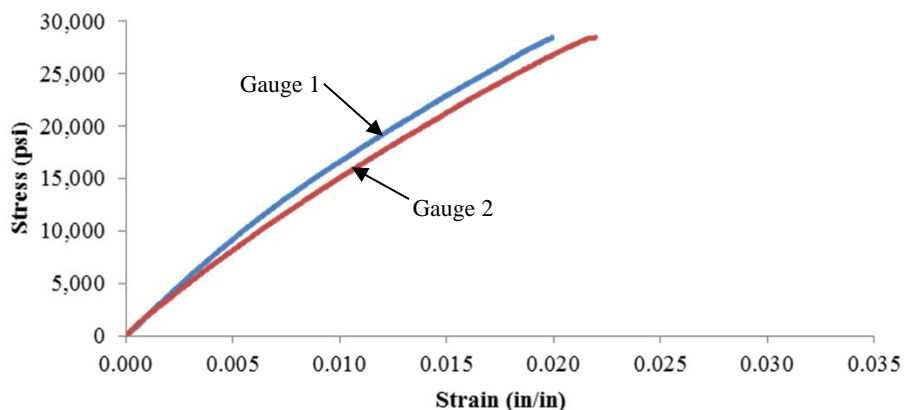
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00842 | 0.00303 | 1,611,153 |
| 2 | 0.00953 | 0.00341 | 1,418,348 |
| Average | | | 1,514,751 |

Stress-Strain 70F_01_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-02-70-FY09
 Test Date: 01/31/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,332 lbs
 Shear Strength, S_{xy} : 29,503 psi
 Shear Modulus, G_{xy} : 1,383,699 psi

Measured Specimen Dimensions:

Thickness, T: 0.7514 in
 Notch Length, N: 0.556 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,466 lbs
 50% Max Load: 6,166 lbs

PICTURE OF SPECIMEN PRE-TEST



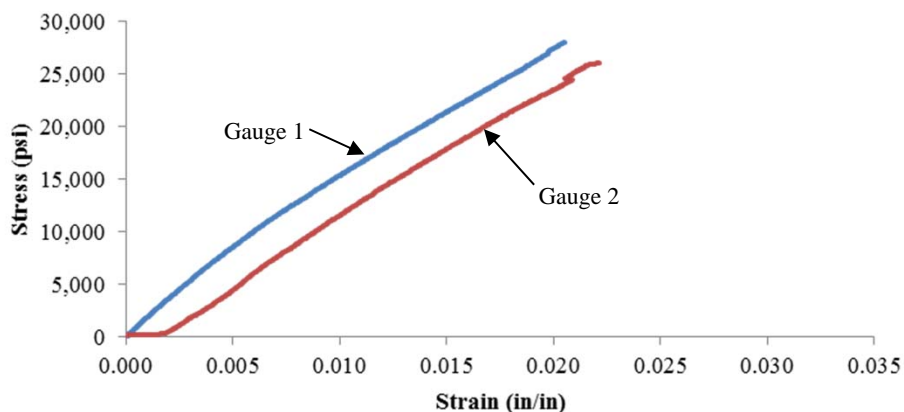
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00951 | 0.00329 | 1,421,678 |
| 2 | 0.01041 | 0.00384 | 1,345,720 |
| Average | | | 1,383,699 |

Stress-Strain Curve 70F_02_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-03-70-FY09
 Test Date: 02/02/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,280 lbs
 Shear Strength, S_{xy} : 29,448 psi
 Shear Modulus, G_{xy} : 1,475,655 psi

Measured Specimen Dimensions:

Thickness, T: 0.7518 in
 Notch Length, N: 0.555 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,456 lbs
 50% Max Load: 6,140 lbs

PICTURE OF SPECIMEN PRE-TEST



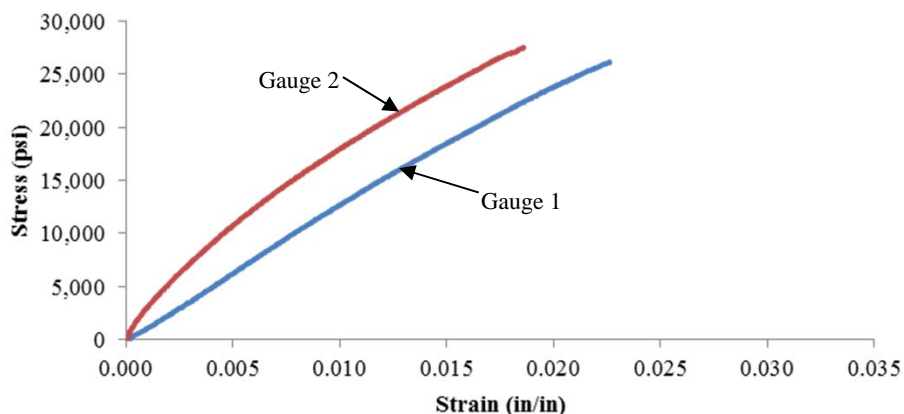
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01165 | 0.00472 | 1,274,067 |
| 2 | 0.00757 | 0.00230 | 1,677,242 |
| Average | | | 1,475,655 |

Stress-Strain Curve 70F_03_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-04-70-FY09
 Test Date: 02/02/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,431 lbs
 Shear Strength, S_{xy} : 29,045 psi
 Shear Modulus, G_{xy} : 1,423,715 psi

Measured Specimen Dimensions:

Thickness, T: 0.7705 in
 Notch Length, N: 0.555 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,486 lbs
 50% Max Load: 6,216 lbs

PICTURE OF SPECIMEN PRE-TEST



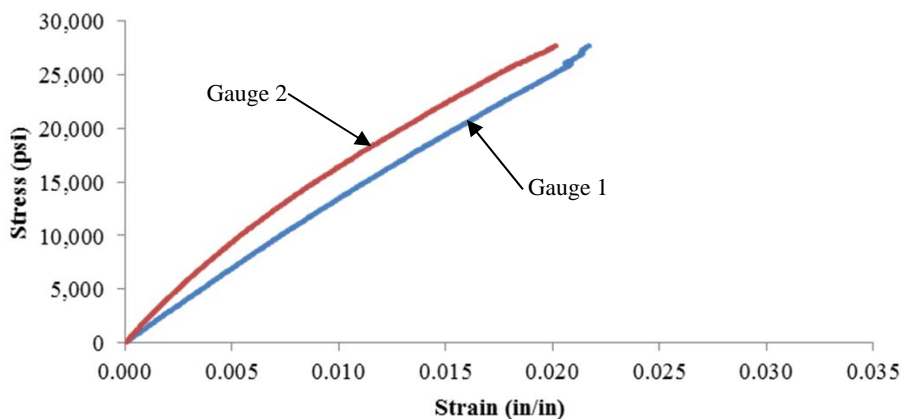
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01083 | 0.00412 | 1,299,216 |
| 2 | 0.00850 | 0.00287 | 1,548,215 |
| Average | | | 1,423,715 |

Stress-Strain Curve 70F_04_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-05-70-FY09
 Test Date: 02/02/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 12,071 lbs
 Shear Strength, S_{xy} : 26,824 psi
 Shear Modulus, G_{xy} : 1,341,577 psi

Measured Specimen Dimensions:

Thickness, T: 0.7586 in
 Notch Length, N: 0.585 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,414 lbs
 50% Max Load: 6,035 lbs

PICTURE OF SPECIMEN PRE-TEST



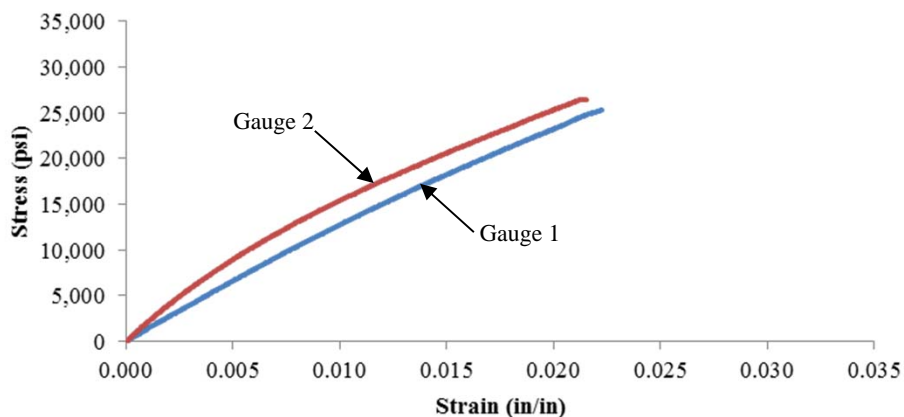
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.01054 | 0.00401 | 1,231,988 |
| 2 | 0.00829 | 0.00274 | 1,451,166 |
| Average | | | 1,341,577 |

Stress-Strain Curve 70F_05_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXY-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 9,667 lbs

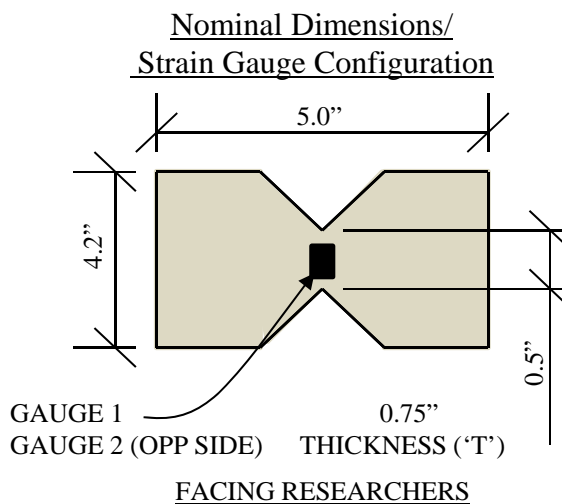
Shear Strength, S_{xy} : 22,764 psi

Shear Modulus, G_{xy} : 1,312,227 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|--------------------------|--------------------------------|-------------------------------|--------------|
| 1 | MAT5-SXY-01-140-FY09 | 9,777 | 22,946 | 1,269,808 | Shear |
| 2 | MAT5-SXY-02-140-FY09 | 9,871 | 23,175 | 1,348,398 | Shear |
| 3 | MAT5-SXY-03-140-FY09 | 9,530 | 22,179 | 1,272,827 | Shear |
| 4 | MAT5-SXY-04-140-FY09 | 9,376 | 22,372 | 1,344,099 | Shear |
| 5 | MAT5-SXY-05-140-FY09 | 9,780 | 23,148 | 1,326,000 | Shear |
| Average | | 9,667 | 22,764 | 1,312,227 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets H-50 to H-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-01-70-FY09
 Test Date: 02/24/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,777 lbs
 Shear Strength, S_{xy} : 22,946 psi
 Shear Modulus, G_{xy} : 1,269,808 psi

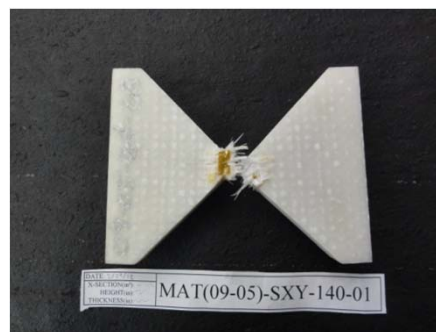
Measured Specimen Dimensions:

Thickness, T : 0.7650 in
 Notch Length, N : 0.5570 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,955 lbs
 50% Max Load: 4,889 lbs

PICTURE OF SPECIMEN PRE-TEST



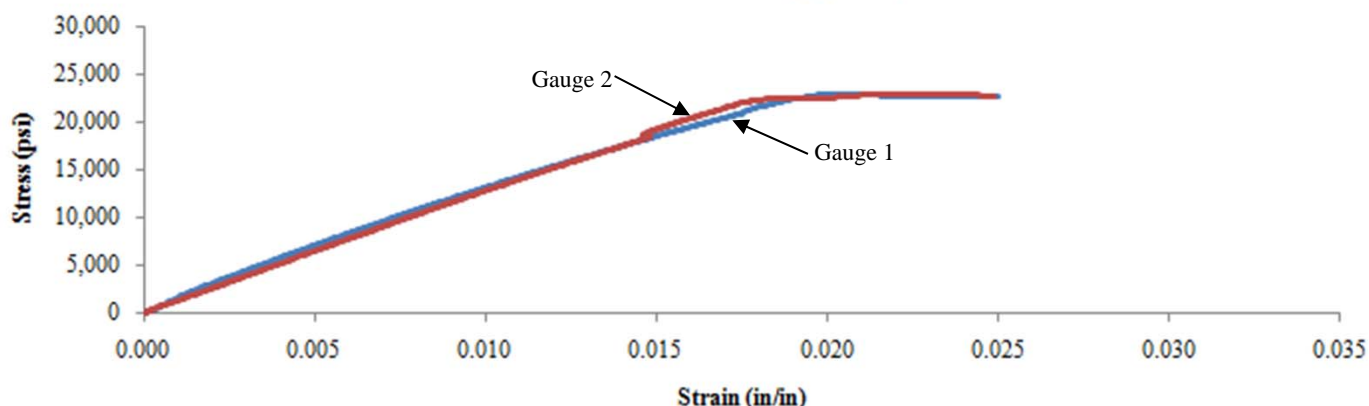
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00854 | 0.00308 | 1,259,685 |
| 2 | 0.00889 | 0.00351 | 1,279,931 |
| Average | | | 1,269,808 |

Stress-Strain Curve 140°F_1_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-02-70-FY09
 Test Date: 03/06/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,871 lbs
 Shear Strength, S_{xy} : 23,175 psi
 Shear Modulus, G_{xy} : 1,348,398 psi

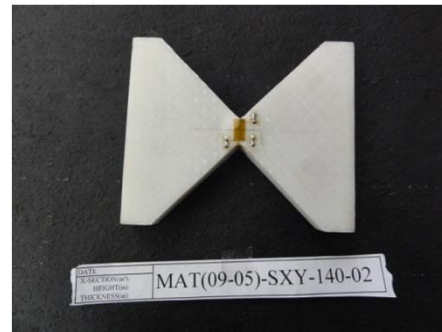
Measured Specimen Dimensions:

Thickness, T: 0.7633 in
 Notch Length, N: 0.5580 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,974 lbs
 50% Max Load: 4,935 lbs

PICTURE OF SPECIMEN PRE-TEST



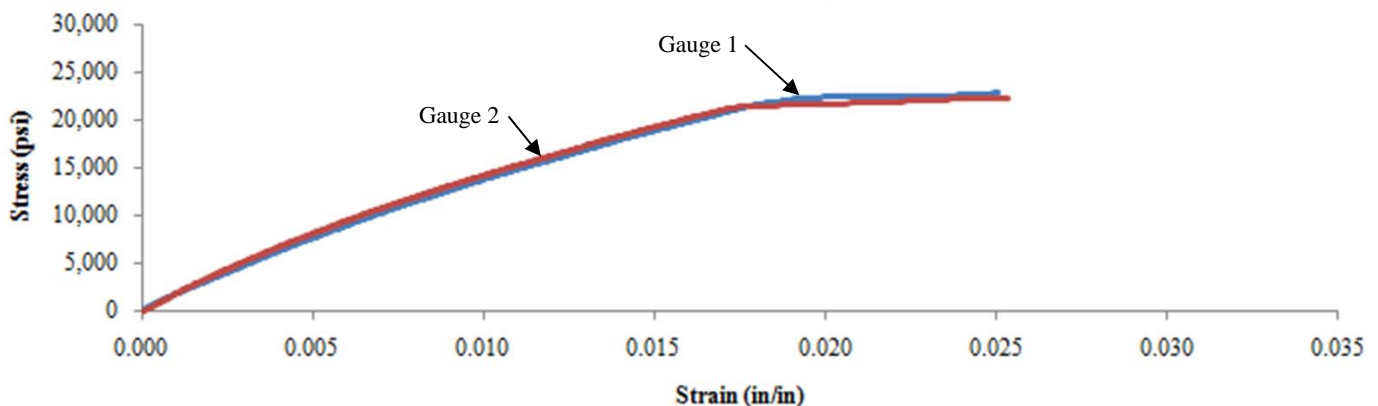
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00810 | 0.00286 | 1,327,518 |
| 2 | 0.00771 | 0.00263 | 1,369,279 |
| Average | | | 1,348,398 |

Stress-Strain Curve 140°F_2_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-03-70-FY09
 Test Date: 03/07/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,530 lbs
 Shear Strength, S_{xy} : 22,179 psi
 Shear Modulus, G_{xy} : 1,272,827 psi

Measured Specimen Dimensions:

Thickness, T: 0.7714 in
 Notch Length, N: 0.5570 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,906 lbs
 50% Max Load: 4,765 lbs

PICTURE OF SPECIMEN PRE-TEST



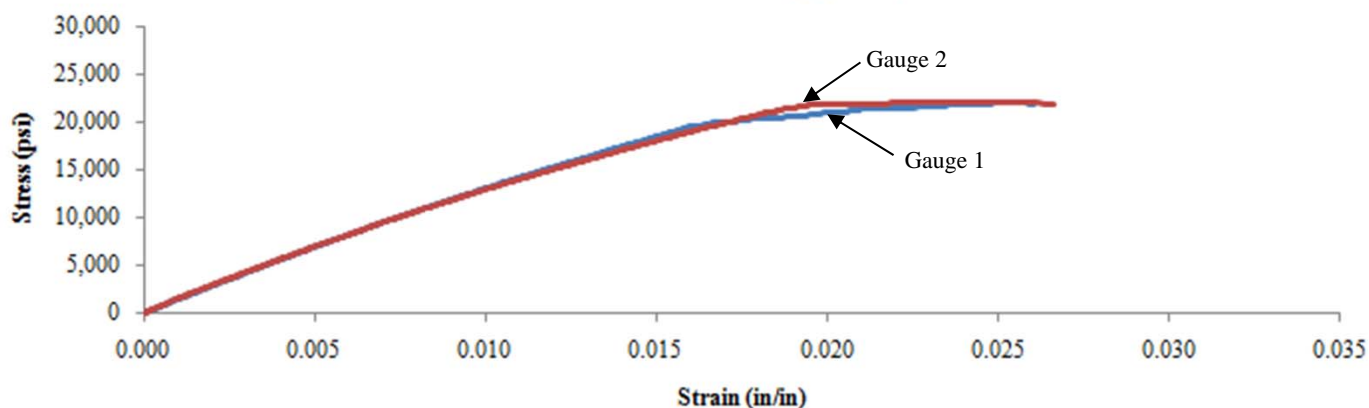
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00831 | 0.00312 | 1,282,435 |
| 2 | 0.00834 | 0.00307 | 1,263,219 |
| Average | | | 1,272,827 |

Stress-Strain Curve 140°F_3_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-04-70-FY09
 Test Date: 03/07/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,376 lbs
 Shear Strength, S_{xy} : 22,372 psi
 Shear Modulus, G_{xy} : 1,344,099 psi

Measured Specimen Dimensions:

Thickness, T: 0.7457 in
 Notch Length, N: 0.5620 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,875 lbs
 50% Max Load: 4,688 lbs

PICTURE OF SPECIMEN PRE-TEST



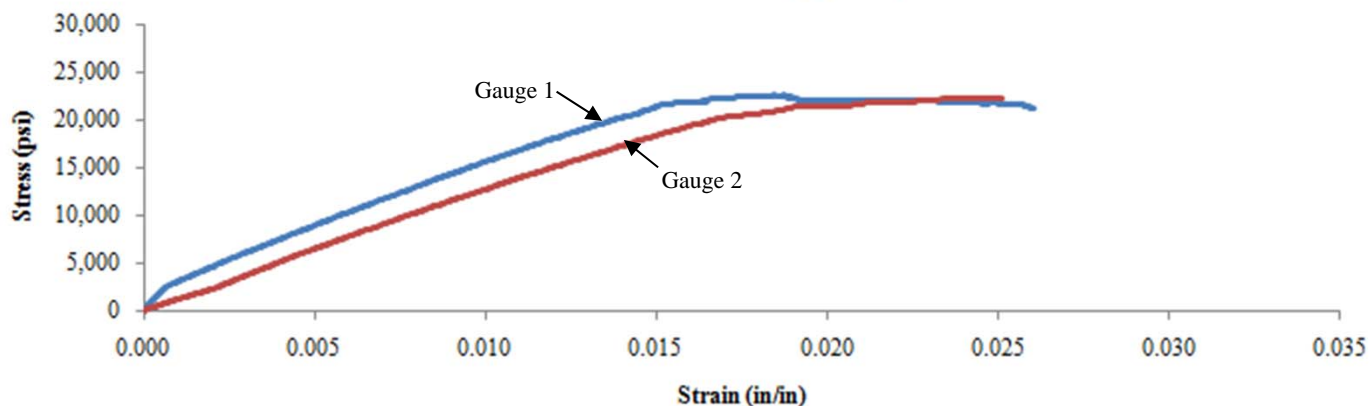
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00667 | 0.00190 | 1,406,686 |
| 2 | 0.00876 | 0.00352 | 1,281,513 |
| Average | | | 1,344,099 |

Stress-Strain Curve 140°F_4_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXY-05-70-FY09
 Test Date: 03/08/2012
 Specimen Received: 10/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,780 lbs
 Shear Strength, S_{xy} : 23,148 psi
 Shear Modulus, G_{xy} : 1,326,000 psi

Measured Specimen Dimensions:

Thickness, T: 0.7640 in
 Notch Length, N: 0.5530 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,956 lbs
 50% Max Load: 4,890 lbs

PICTURE OF SPECIMEN PRE-TEST



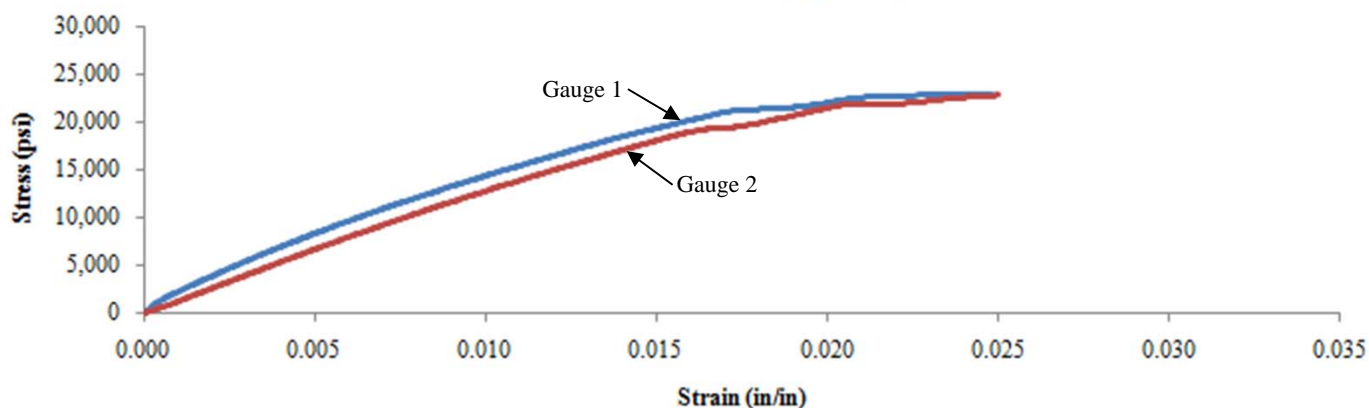
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00746 | 0.00242 | 1,376,361 |
| 2 | 0.00887 | 0.00342 | 1,275,640 |
| Average | | | 1,326,000 |

Stress-Strain Curve 140°F_5_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

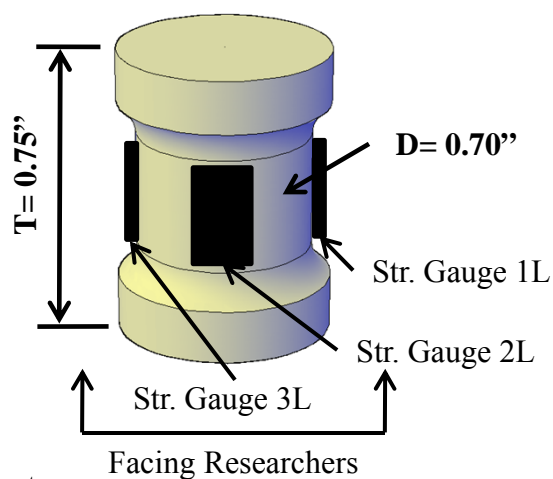
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-TZ-N40-FY09
Material: Applied Poleramics SC-15, S2 Glass
Nominal Temperature: -40°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 1,795 lbs
 Tensile Strength, ST_z : 4,476 psi
 Tensile Modulus, E_z : 1,272,445 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT5-TZ-1-N40-FY09 | 1,650 | 3,917 | 1,276,615 | Rupture |
| MAT5-TZ-2-N40-FY09 | 1,588 | 3,767 | 1,320,387 | Rupture |
| MAT5-TZ-3-N40-FY09 | 1,820 | 4,716 | 1,232,494 | Rupture |
| MAT5-TZ-4-N40-FY09 | 1,954 | 4,992 | 1,286,815 | Rupture |
| MAT5-TZ-5-N40-FY09 | 1,964 | 4,989 | 1,245,914 | Rupture |
| Average | 1,795 | 4,476 | 1,272,445 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-56 to H-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-1-N40-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,917 psi
 Tensile Modulus, E_z : 1,276,615 psi

Measured Specimen Dimensions:

Diameter, D: 0.732 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,959 psi
 20% Max Stress: 783 psi

PICTURE OF SPECIMEN PRE-TEST



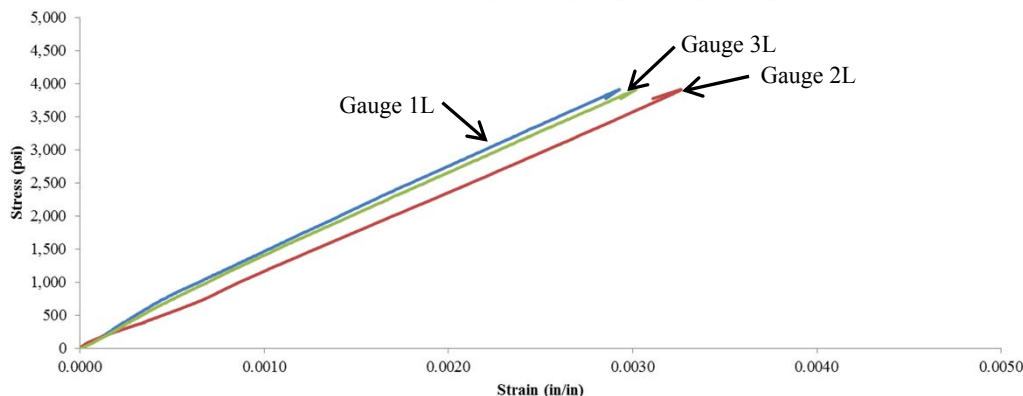
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001376 | 0.000476 | 1,306,332 |
| 2L | 0.001660 | 0.000702 | 1,226,837 |
| 3L | 0.001434 | 0.000527 | 1,296,674 |
| Average | | | 1,276,615 |

Stress-Strain Curve_-40°F_1_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-2-N40-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,767 psi
 Tensile Modulus, E_z : 1,320,387 psi

Measured Specimen Dimensions:

Diameter, D: 0.733 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,884 psi
 20% Max Stress: 753 psi

PICTURE OF SPECIMEN PRE-TEST



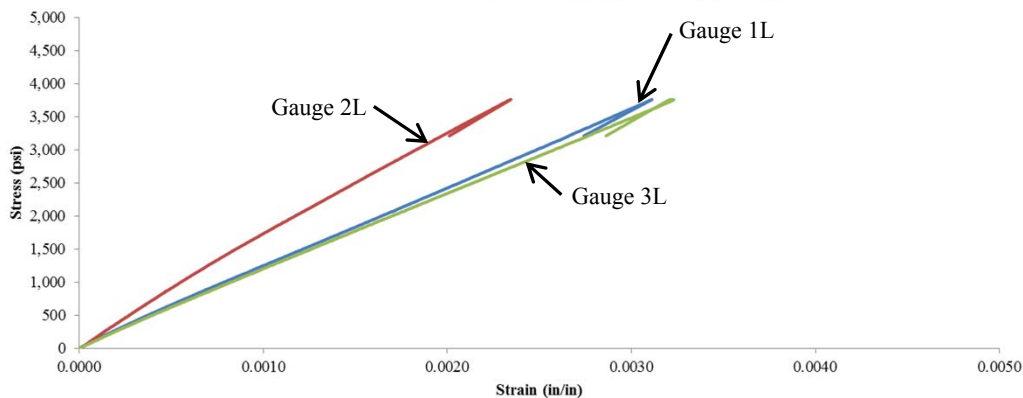
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001542 | 0.000575 | 1,169,247 |
| 2L | 0.001096 | 0.000409 | 1,646,227 |
| 3L | 0.001595 | 0.000608 | 1,145,687 |
| Average | | | 1,320,387 |

Stress-Strain Curve_ -40°F_2_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-3-N40-FY09**
 Test Date: 12/2/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

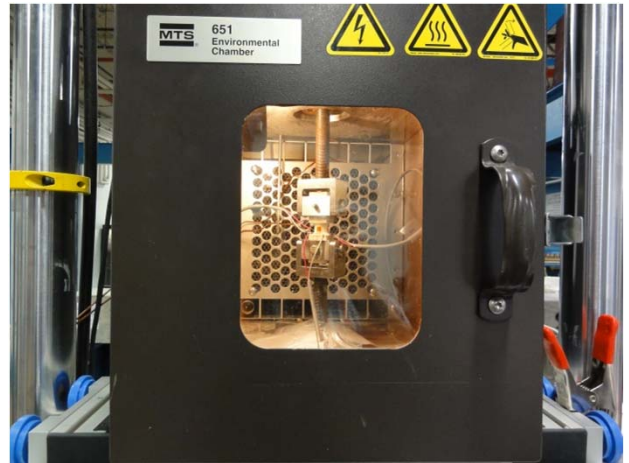
Average Material Properties:

Tensile Strength, ST_z : 4,716 psi
 Tensile Modulus, E_z : 1,232,494 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,358 psi
 20% Max Stress: 943 psi

PICTURE OF SPECIMEN PRE-TEST



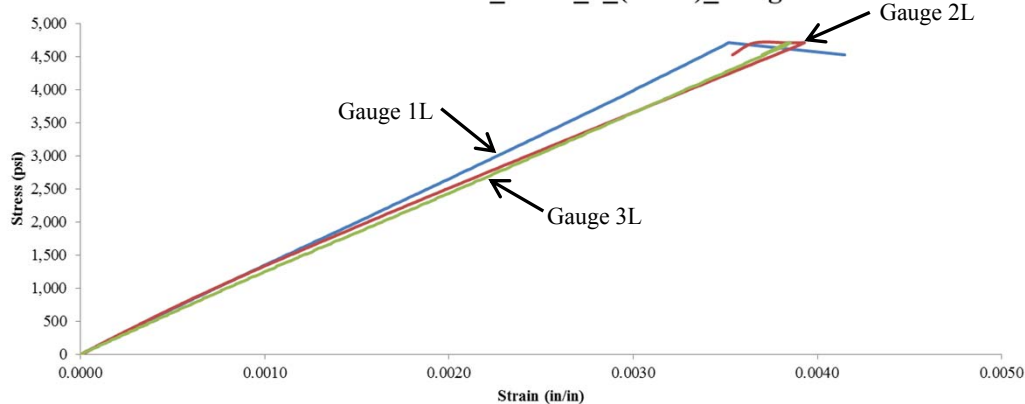
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001773 | 0.000688 | 1,303,762 |
| 2L | 0.001864 | 0.000682 | 1,197,765 |
| 3L | 0.001930 | 0.000747 | 1,195,956 |
| Average | | | 1,232,494 |

Stress-Strain Curve_-40°F_3_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-4-N40-FY09**
 Test Date: 12/2/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 4,992 psi
 Tensile Modulus, E_z : 1,286,815 psi

Measured Specimen Dimensions:

Diameter, D: 0.706 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,496 psi
 20% Max Stress: 998 psi

PICTURE OF SPECIMEN PRE-TEST

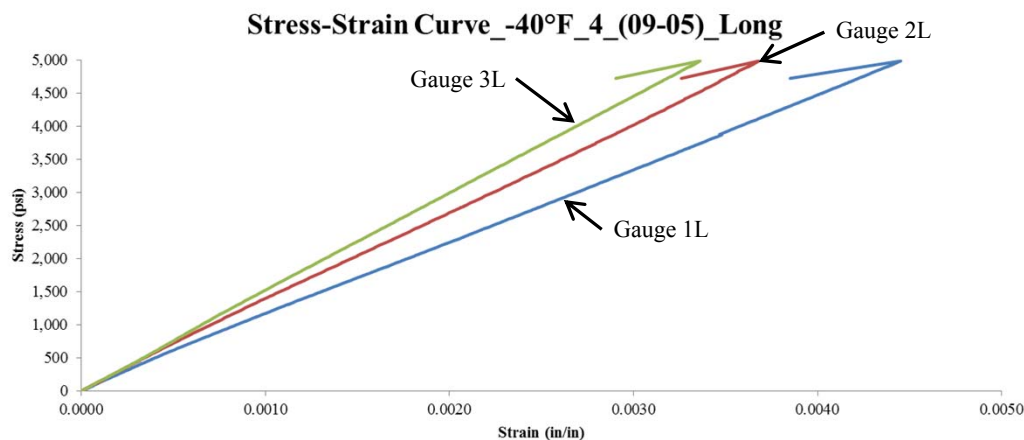


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002229 | 0.000838 | 1,076,302 |
| 2L | 0.001850 | 0.000701 | 1,303,277 |
| 3L | 0.001661 | 0.000650 | 1,480,866 |
| Average | | | 1,286,815 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-5-N40-FY09**
 Test Date: 12/2/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

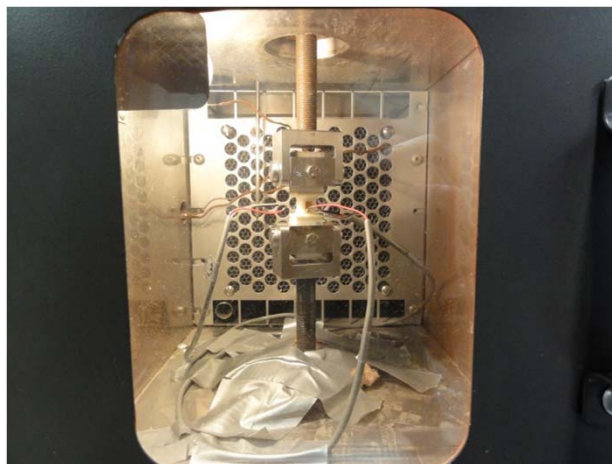
Average Material Properties:

Tensile Strength, ST_z : 4,989 psi
 Tensile Modulus, E_z : 1,245,914 psi

Measured Specimen Dimensions:

Diameter, D: 0.708 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,494 psi
 20% Max Stress: 998 psi

PICTURE OF SPECIMEN PRE-TEST

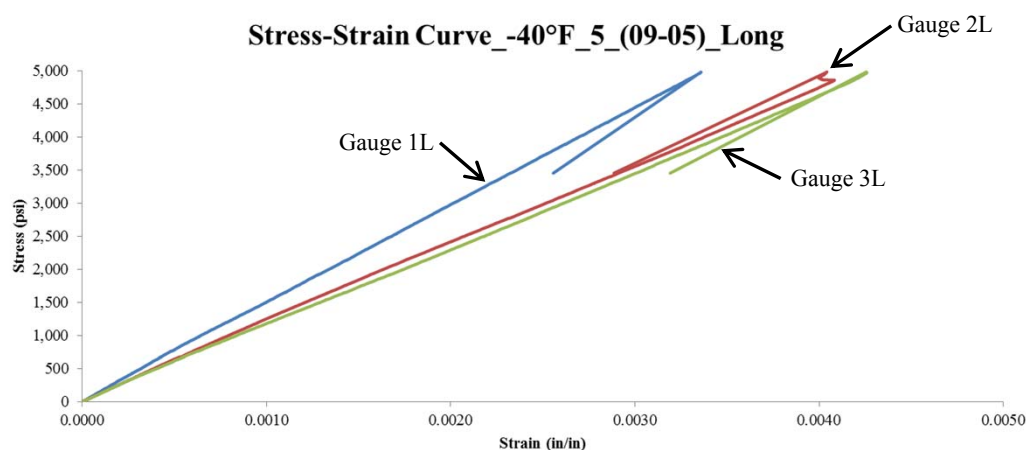


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001673 | 0.000639 | 1,447,585 |
| 2L | 0.002065 | 0.000790 | 1,173,532 |
| 3L | 0.002174 | 0.000834 | 1,116,625 |
| Average | | | 1,245,914 |



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

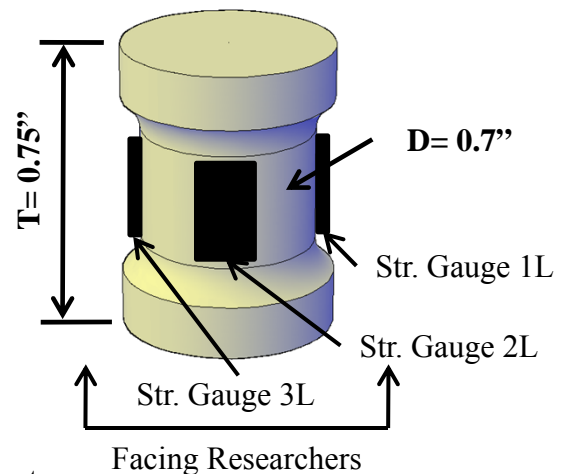
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT5-TZ-70-FY09**
 Material: **Applied Poleramics SC-15, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **ST_z , E_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **1,663** lbs
 Tensile Strength, ST_z : **3,947** psi
 Tensile Modulus, E_z : **1,248,494** psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT5-TZ-1-70-FY09 | 1,622 | 3,863 | 1,305,618 | Rupture |
| MAT5-TZ-2-70-FY09 | 1,755 | 4,155 | 1,247,328 | Rupture |
| MAT5-TZ-3-70-FY09 | 1,601 | 3,796 | 1,203,181 | Rupture |
| MAT5-TZ-4-70-FY09 | 1,669 | 3,958 | 1,281,342 | Rupture |
| MAT5-TZ-5-70-FY09 | 1,667 | 3,964 | 1,205,003 | Rupture |
| Average | 1,663 | 3,947 | 1,248,494 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-62 to H-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-1-70-FY09**
 Test Date: 11/11/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

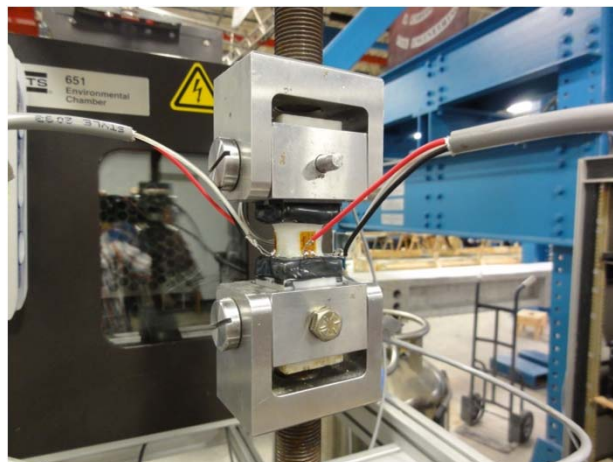
Average Material Properties:

Tensile Strength, ST_z : 3,863 psi
 Tensile Modulus, E_z : 1,305,618 psi

Measured Specimen Dimensions:

Diameter, D: 0.731 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,931 psi
 20% Max Stress: 773 psi

PICTURE OF SPECIMEN PRE-TEST



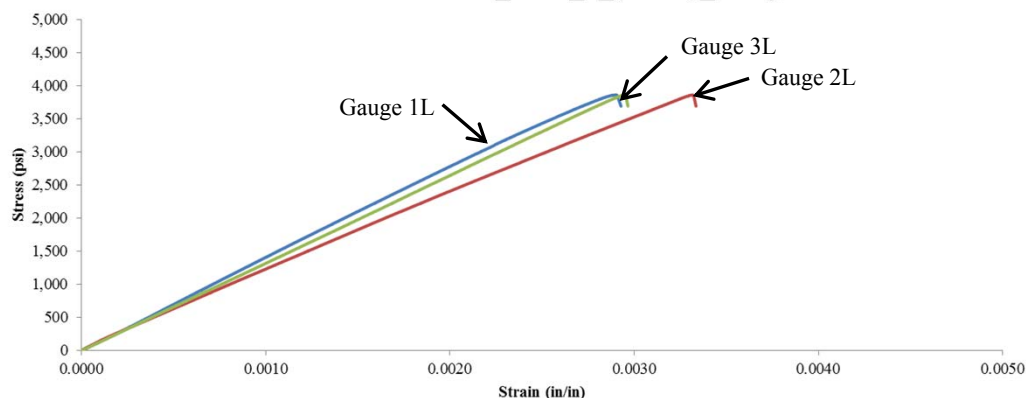
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001376 | 0.000553 | 1,407,609 |
| 2L | 0.001588 | 0.000616 | 1,191,377 |
| 3L | 0.001465 | 0.000586 | 1,317,868 |
| Average | | | 1,305,618 |

Stress-Strain Curve_70°F_1_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-2-70-FY09**
 Test Date: 11/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

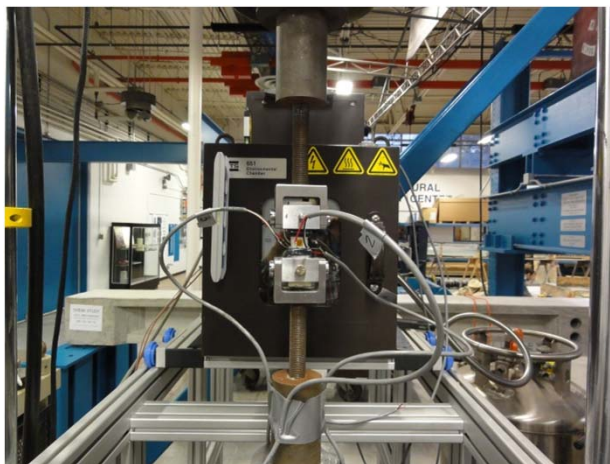
Average Material Properties:

Tensile Strength, ST_z : 4,155 psi
 Tensile Modulus, E_z : 1,247,328 psi

Measured Specimen Dimensions:

Diameter, D: 0.733 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 2,077 psi
 20% Max Stress: 831 psi

PICTURE OF SPECIMEN PRE-TEST



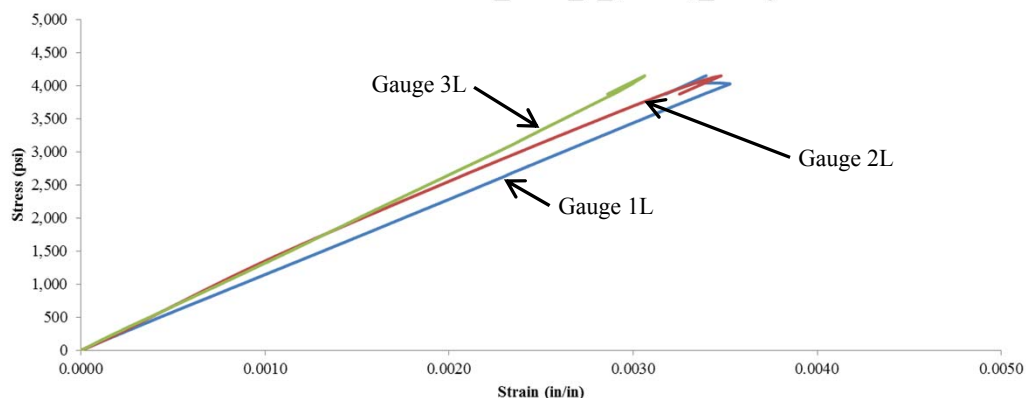
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001816 | 0.000720 | 1,137,027 |
| 2L | 0.001591 | 0.000613 | 1,274,676 |
| 3L | 0.001562 | 0.000625 | 1,330,281 |
| Average | | | 1,247,328 |

Stress-Strain Curve_70°F_2_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-3-70-FY09**
 Test Date: 11/14/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,796 psi
 Tensile Modulus, E_z : 1,203,181 psi

Measured Specimen Dimensions:

Diameter, D: 0.733 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,898 psi
 20% Max Stress: 759 psi

PICTURE OF SPECIMEN PRE-TEST



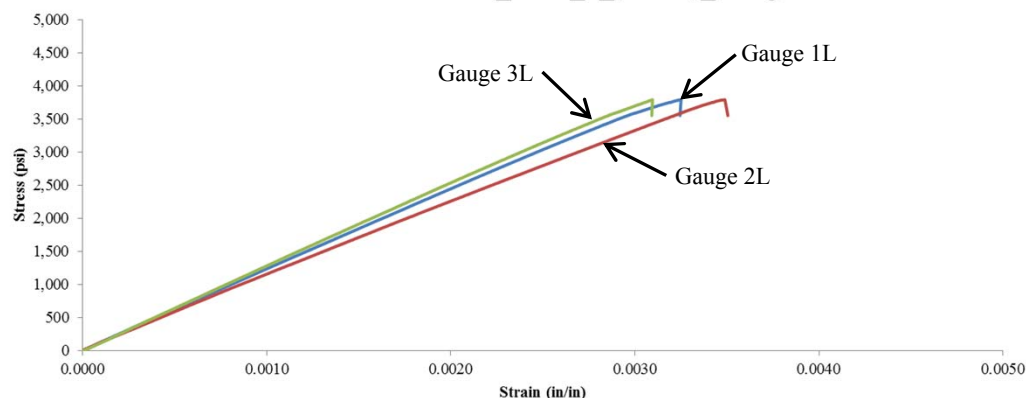
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001543 | 0.000610 | 1,220,472 |
| 2L | 0.001666 | 0.000646 | 1,116,516 |
| 3L | 0.001486 | 0.000591 | 1,272,556 |
| Average | | | 1,203,181 |

Stress-Strain Curve_70°F_3_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-4-70-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

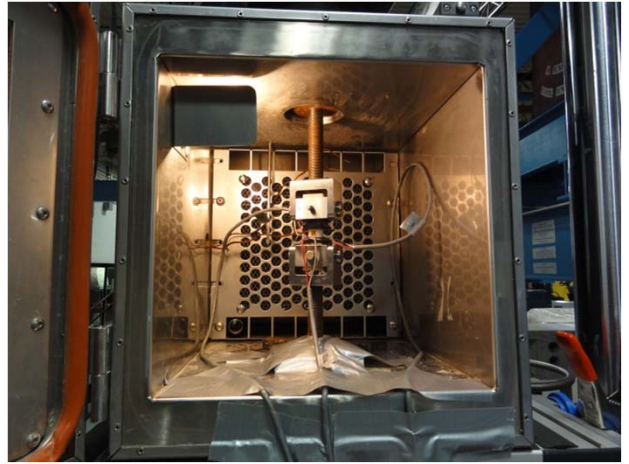
Average Material Properties:

Tensile Strength, ST_z : 3,958 psi
 Tensile Modulus, E_z : 1,281,342 psi

Measured Specimen Dimensions:

Diameter, D: 0.733 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,979 psi
 20% Max Stress: 792 psi

PICTURE OF SPECIMEN PRE-TEST



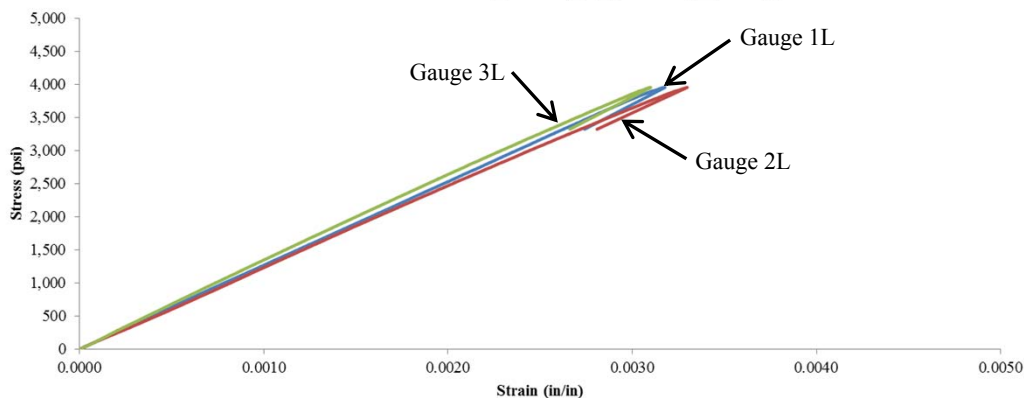
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001560 | 0.000620 | 1,264,138 |
| 2L | 0.001592 | 0.000650 | 1,260,542 |
| 3L | 0.001480 | 0.000580 | 1,319,346 |
| Average | | | 1,281,342 |

Stress-Strain Curve_70°F_4_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-5-70-FY09**
 Test Date: 11/16/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

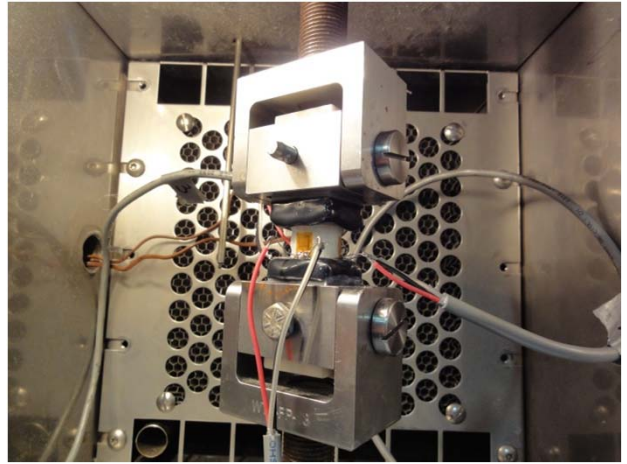
Average Material Properties:

Tensile Strength, ST_z : 3,964 psi
 Tensile Modulus, E_z : 1,205,003 psi

Measured Specimen Dimensions:

Diameter, D: 0.732 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,982 psi
 20% Max Stress: 793 psi

PICTURE OF SPECIMEN PRE-TEST



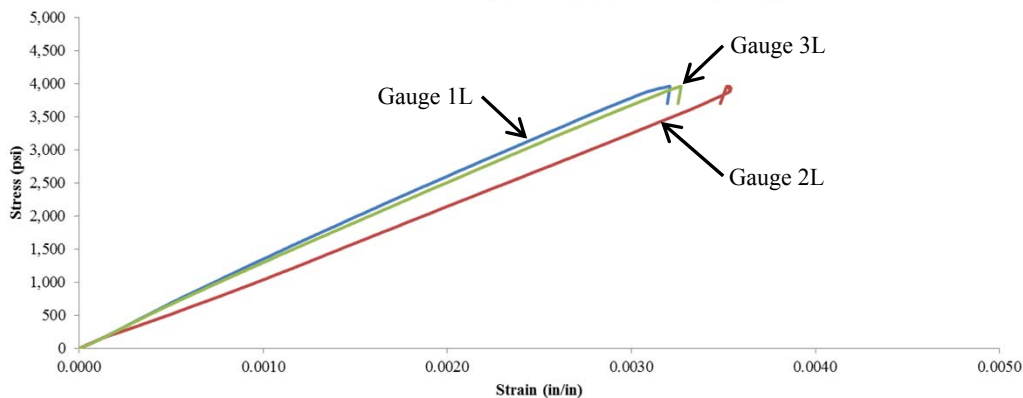
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001492 | 0.000572 | 1,291,304 |
| 2L | 0.001850 | 0.000763 | 1,094,132 |
| 3L | 0.001559 | 0.000592 | 1,229,572 |
| Average | | | 1,205,003 |

Stress-Strain Curve_70°F_5_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

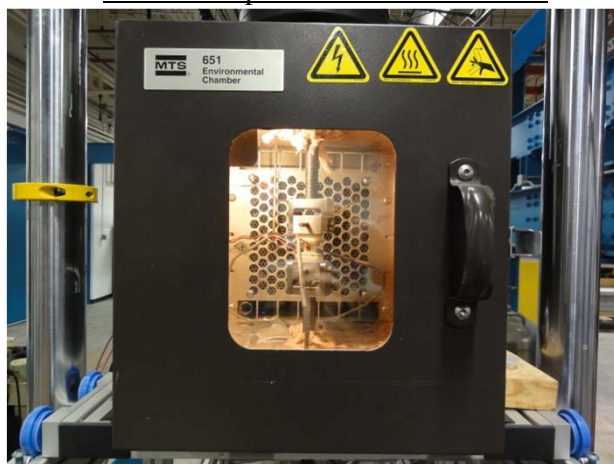
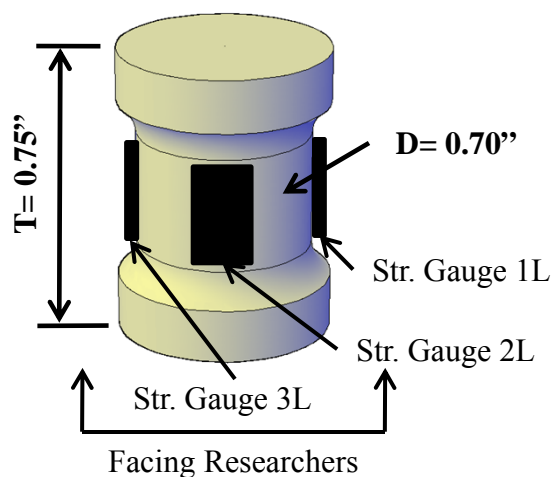
TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-TZ-140-FY09
Material: Applied Poleramics SC-15, S2 Glass
Nominal Temperature: 140°F
Properties Measured: ST_z , E_z
Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 1,315 lbs
 Tensile Strength, ST_z : 3,417 psi
 Tensile Modulus, E_z : 1,034,477 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT5-TZ-1-140-FY09 | 1,387 | 3,605 | 1,010,537 | Rupture |
| MAT5-TZ-2-140-FY09 | 1,337 | 3,475 | 1,117,755 | Rupture |
| MAT5-TZ-3-140-FY09 | 1,117 | 2,902 | 976,577 | Rupture |
| MAT5-TZ-4-140-FY09 | 1,413 | 3,671 | 1,017,009 | Rupture |
| MAT5-TZ-5-140-FY09 | 1,320 | 3,431 | 1,050,508 | Rupture |
| Average | 1,315 | 3,417 | 1,034,477 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-68 to H-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-1-140-FY09**
 Test Date: 2/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,605 psi
 Tensile Modulus, E_z : 1,010,537 psi

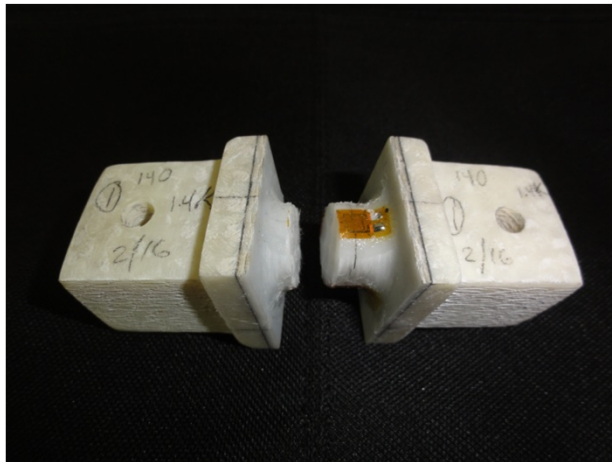
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,803 psi
 20% Max Stress: 721 psi

PICTURE OF SPECIMEN PRE-TEST



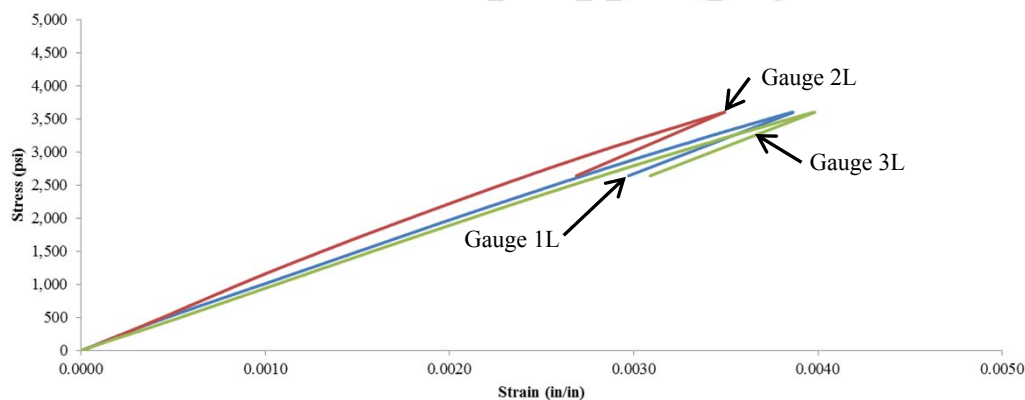
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001818 | 0.000691 | 959,344 |
| 2L | 0.001590 | 0.000624 | 1,119,716 |
| 3L | 0.001901 | 0.000766 | 952,551 |
| Average | | | 1,010,537 |

Stress-Strain Curve_140°F_1_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-2-140-FY09**
 Test Date: 2/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,475 psi
 Tensile Modulus, E_z : 1,117,755 psi

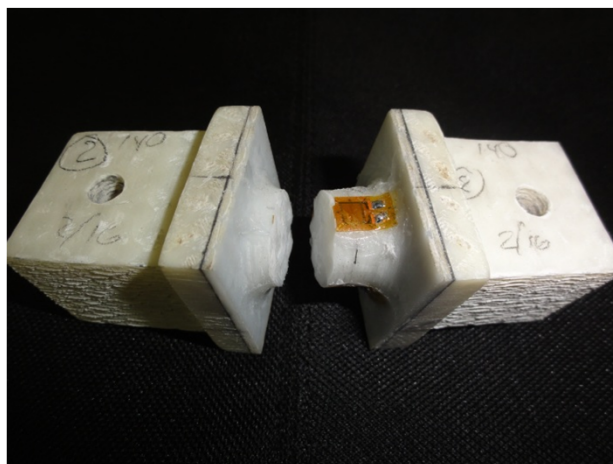
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,737 psi
 20% Max Stress: 695 psi

PICTURE OF SPECIMEN PRE-TEST



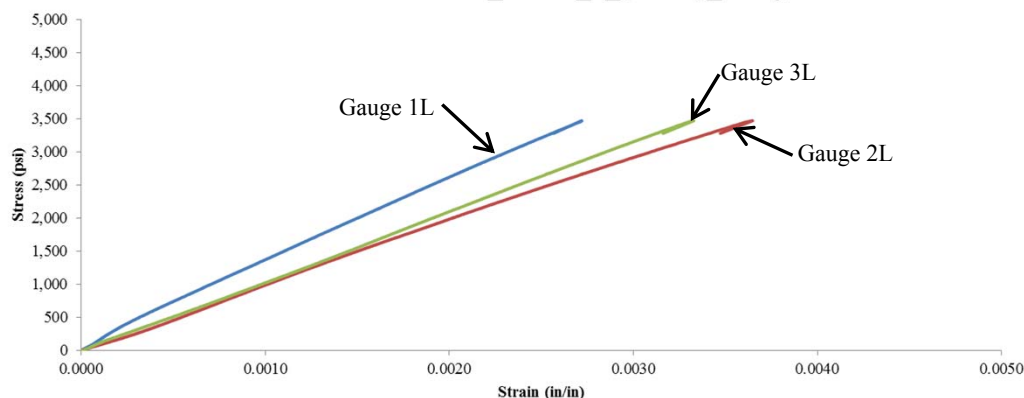
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001285 | 0.000464 | 1,268,999 |
| 2L | 0.001741 | 0.000723 | 1,024,222 |
| 3L | 0.001665 | 0.000681 | 1,060,045 |
| Average | | | 1,117,755 |

Stress-Strain Curve_140°F_2_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-3-140-FY09**
 Test Date: 2/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

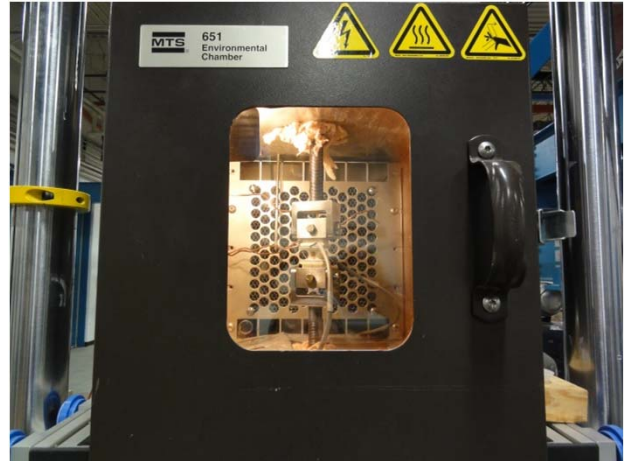
Average Material Properties:

Tensile Strength, ST_z : 2,902 psi
 Tensile Modulus, E_z : 976,577 psi

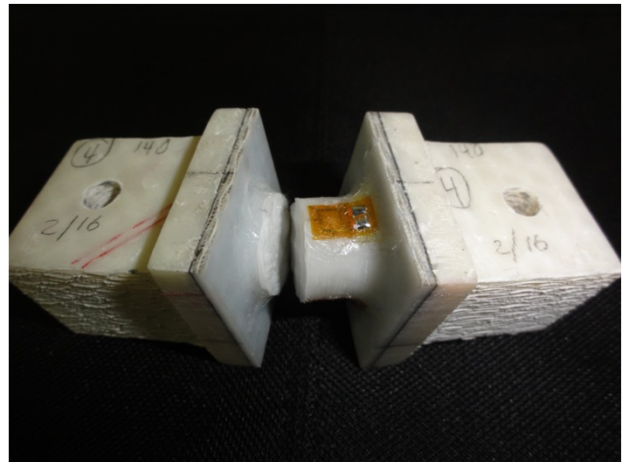
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,451 psi
 20% Max Stress: 580 psi

PICTURE OF SPECIMEN PRE-TEST



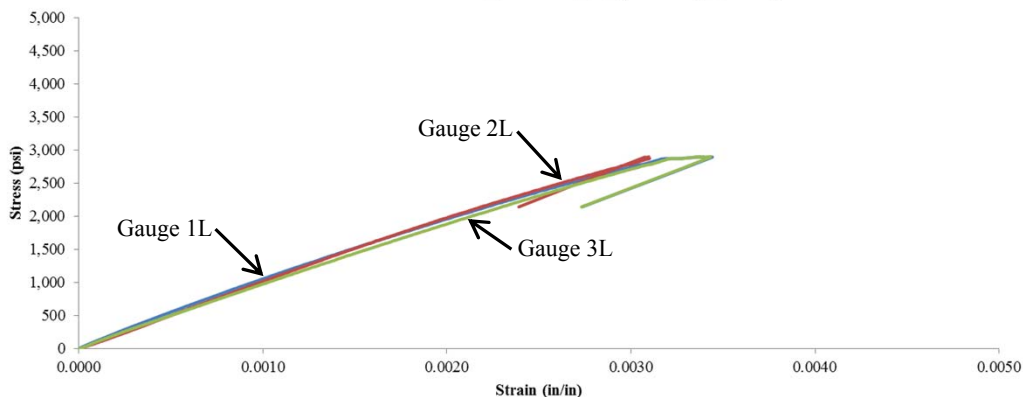
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001422 | 0.000527 | 972,941 |
| 2L | 0.001433 | 0.000576 | 1,015,794 |
| 3L | 0.001511 | 0.000586 | 940,995 |
| Average | | | 976,577 |

Stress-Strain Curve_140°F_3_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-4-140-FY09**
 Test Date: 2/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

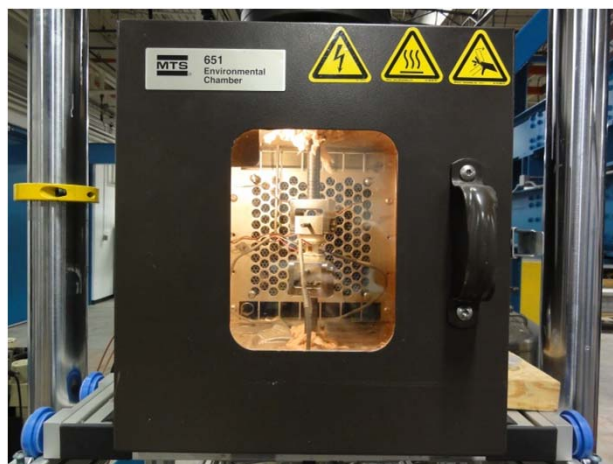
Average Material Properties:

Tensile Strength, ST_z : 3,671 psi
 Tensile Modulus, E_z : 1,017,009 psi

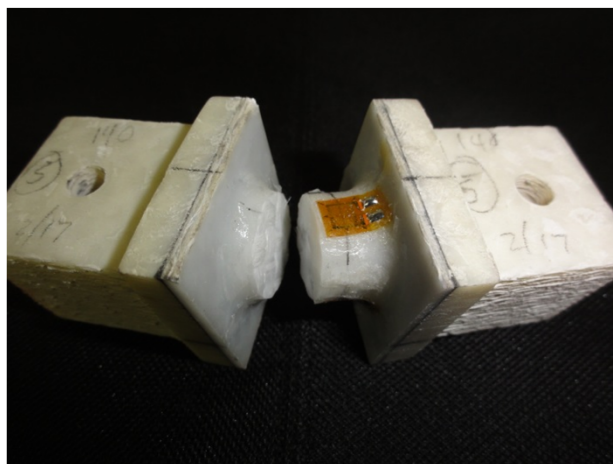
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,835 psi
 20% Max Stress: 734 psi

PICTURE OF SPECIMEN PRE-TEST



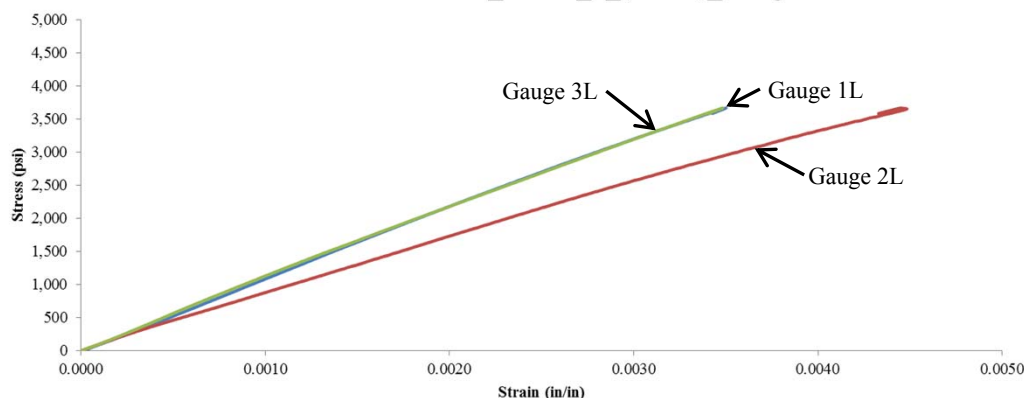
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001674 | 0.000687 | 1,115,490 |
| 2L | 0.002118 | 0.000829 | 854,056 |
| 3L | 0.001662 | 0.000644 | 1,081,480 |
| Average | | | 1,017,009 |

Stress-Strain Curve_140°F_4_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-TZ-5-140-FY09**
 Test Date: 2/23/2012
 Specimen Received: 7/07/2011
 Properties Measured: ST_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,431 psi
 Tensile Modulus, E_z : 1,050,508 psi

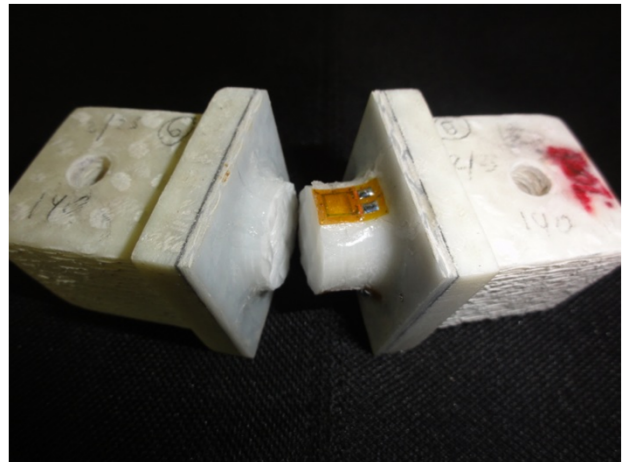
Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,716 psi
 20% Max Stress: 686 psi

PICTURE OF SPECIMEN PRE-TEST



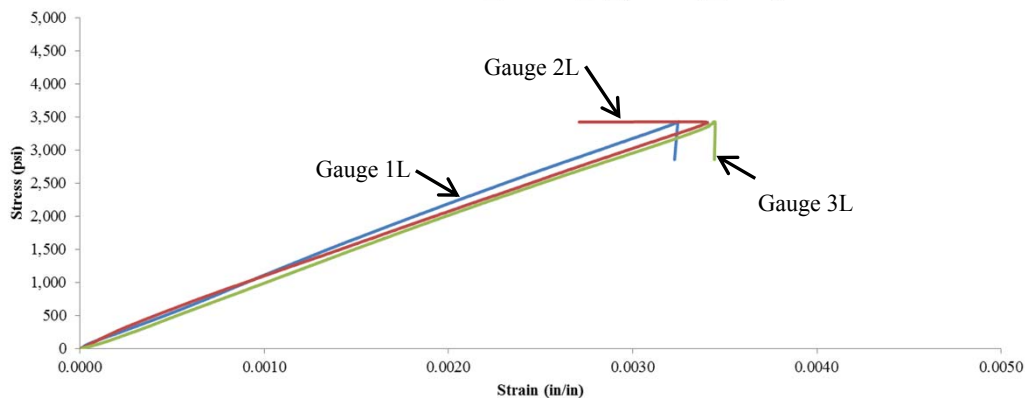
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001542 | 0.000629 | 1,127,425 |
| 2L | 0.001627 | 0.000582 | 984,180 |
| 3L | 0.001695 | 0.000706 | 1,039,918 |
| Average | | | 1,050,508 |

Stress-Strain Curve_140°F_5_(09-05)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

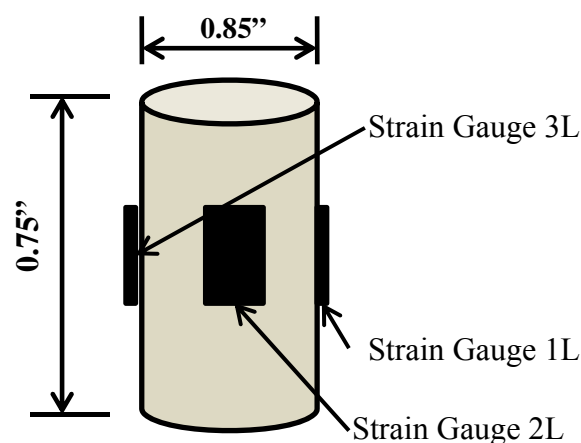
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-CZ-N40-FY09
 Material: Applied Poleramics SC-15, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 62,022 lbs
 Compressive Strength, SC_z : 110,379 psi
 Compressive Modulus, E_z : 1,410,032 psi
 Ultimate Strain, ϵ_z : 0.080 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT5-CZ-01-N40-FY09 | 57,574 | 102,423 | 1,430,035 | 0.0720 | Rupture |
| MAT5-CZ-02-N40-FY09 | 63,691 | 113,304 | 1,698,802 | 0.0675 | Rupture |
| MAT5-CZ-03-N40-FY09 | 64,208 | 113,955 | 1,367,697 | 0.0834 | Rupture |
| MAT5-CZ-04-N40-FY09 | 64,692 | 114,814 | 1,326,365 | 0.0871 | Rupture |
| MAT5-CZ-05-N40-FY09 | 59,945 | 107,401 | 1,227,259 | 0.0879 | Rupture |
| Average | 62,022 | 110,379 | 1,410,032 | 0.080 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test ConditionNominal Dimensions/
Strain Gauge ConfigurationNotes:

- 1) Reference H-74 to H-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-01-N40-FY09**
 Test Date: 5/9/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

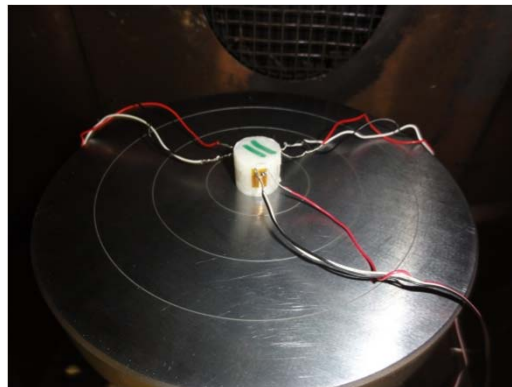
Average Material Properties:

Maximum Load, P_z : 57,574 lbs
 Compressive Strength, SC_z : 102,423 psi
 Compressive Modulus, E_z : 1,430,035 psi
 Ultimate Strain, ϵ_z : 0.072 in/in

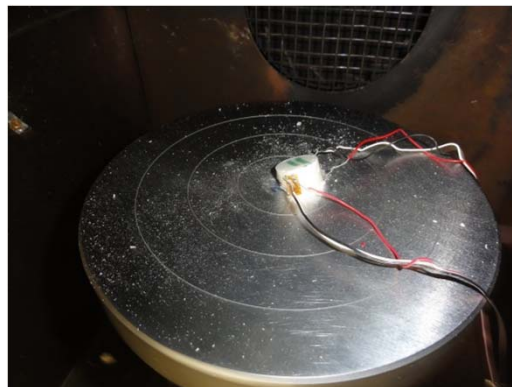
Measured Specimen Dimensions:

Thickness, T: 0.750 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,515 lbs
 50% Max Load: 28,787 lbs

PICTURE OF SPECIMEN PRE-TEST



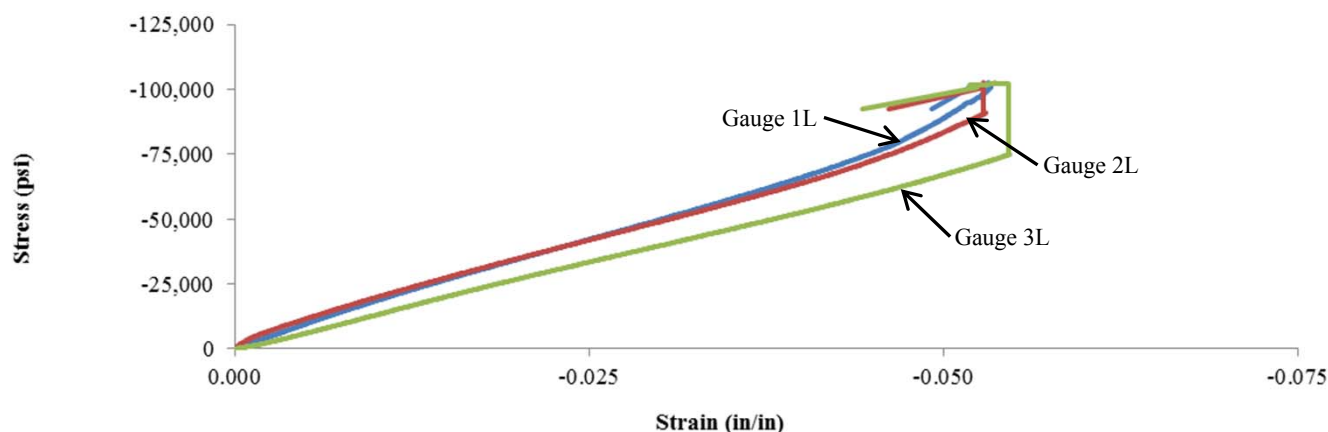
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03094 | 0.01109 | 1,547,899 |
| 2L | 0.03157 | 0.01037 | 1,449,769 |
| 3L | 0.03895 | 0.01518 | 1,292,437 |
| Average | | | 1,430,035 |

Stress-Strain Curve (09-05)_{-40°F}_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-02-N40-FY09**
 Test Date: 5/10/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

Maximum Load, P_z : 63,691 lbs
 Compressive Strength, SC_z : 113,304 psi
 Compressive Modulus, E_z : 1,698,802 psi
 Ultimate Strain, ϵ_z : 0.067 in/in

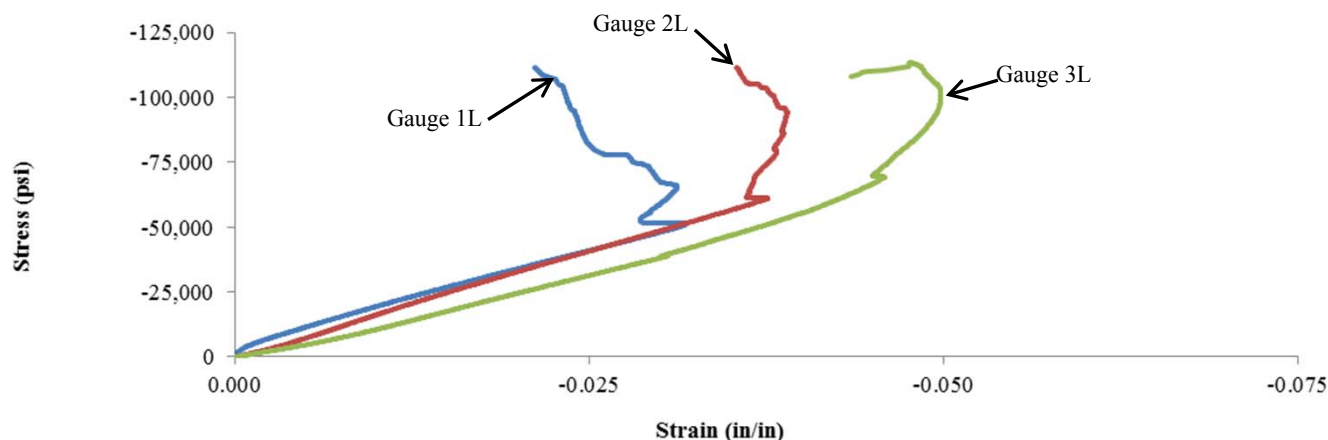
Measured Specimen Dimensions:

Thickness, T : 0.751 in
 Diameter, D : 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 12,738 lbs
 50% Max Load: 31,845 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.02943 | 0.01213 | 1,965,103 |
| 2L | 0.03506 | 0.01371 | 1,592,380 |
| 3L | 0.04072 | 0.01863 | 1,538,923 |
| Average | | | 1,698,802 |

Stress-Strain Curve (09-05)_{-40°F}_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-03-N40-FY09**
 Test Date: 5/10/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

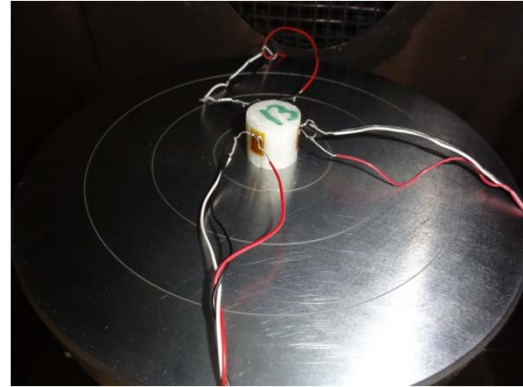
Average Material Properties:

Maximum Load, P_z : 64,208 lbs
 Compressive Strength, SC_z : 113,955 psi
 Compressive Modulus, E_z : 1,367,697 psi
 Ultimate Strain, ϵ_z : 0.083 in/in

Measured Specimen Dimensions:

Thickness, T : 0.773 in
 Diameter, D : 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 12,842 lbs
 50% Max Load: 32,104 lbs

PICTURE OF SPECIMEN PRE-TEST



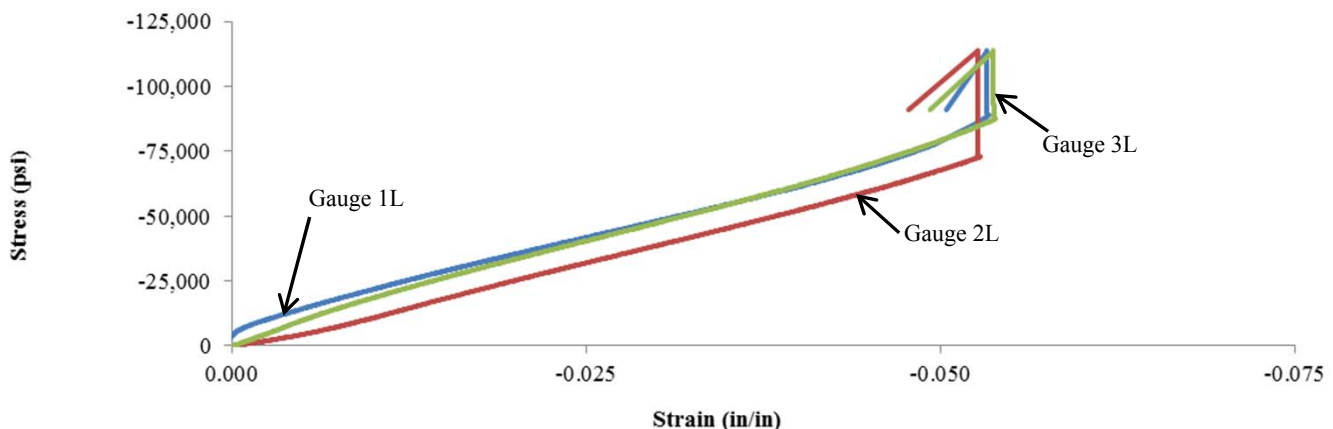
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03685 | 0.01071 | 1,307,995 |
| 2L | 0.04326 | 0.01833 | 1,371,271 |
| 3L | 0.03676 | 0.01275 | 1,423,824 |
| Average | | | 1,367,697 |

Stress-Strain Curve (09-05)_{-40°F}_{03}



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-04-N40-FY09**
 Test Date: 5/11/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

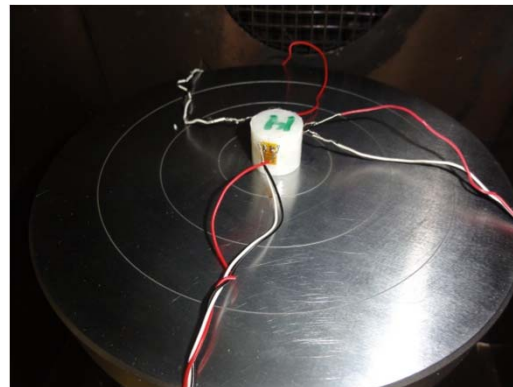
Average Material Properties:

Maximum Load, P_z : 64,692 lbs
 Compressive Strength, SC_z : 114,814 psi
 Compressive Modulus, E_z : 1,326,365 psi
 Ultimate Strain, ϵ_z : 0.087 in/in

Measured Specimen Dimensions:

Thickness, T: 0.760 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 12,938 lbs
 50% Max Load: 32,346 lbs

PICTURE OF SPECIMEN PRE-TEST



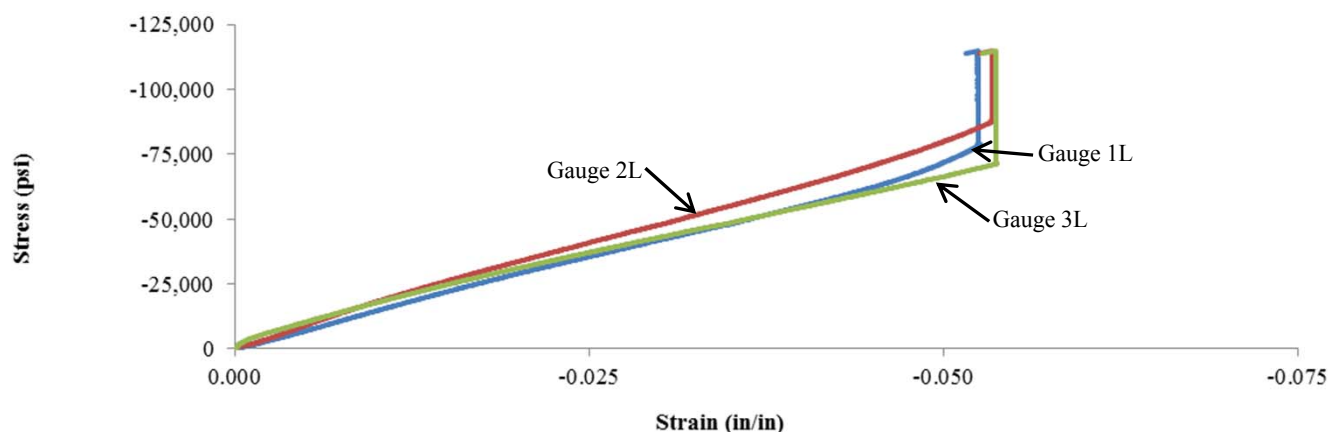
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.04174 | 0.01566 | 1,321,016 |
| 2L | 0.03652 | 0.01295 | 1,461,309 |
| 3L | 0.04250 | 0.01372 | 1,196,771 |
| Average | | | 1,326,365 |

Stress-Strain Curve (09-05)_{-40°F}_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-05-N40-FY09**
 Test Date: 5/11/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 59,945 lbs
 Compressive Strength, SC_z : 107,401 psi
 Compressive Modulus, E_z : 1,227,259 psi
 Ultimate Strain, ϵ_z : 0.088 in/in

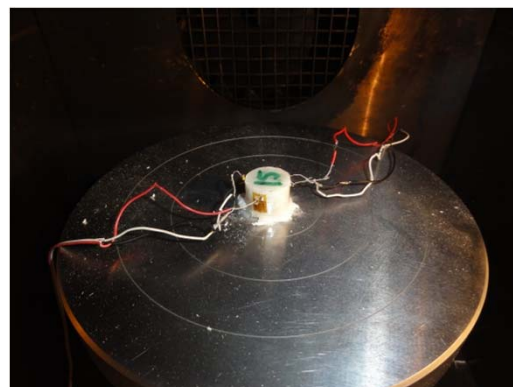
Measured Specimen Dimensions:

Thickness, T: 0.751 in
 Diameter, D: 0.843 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 11,989 lbs
 50% Max Load: 29,972 lbs

PICTURE OF SPECIMEN PRE-TEST



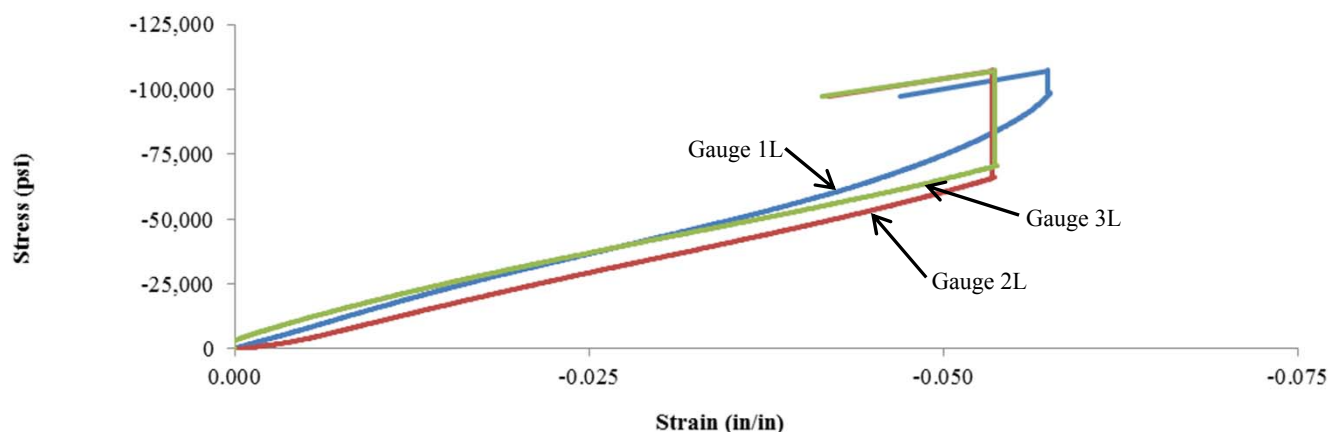
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03792 | 0.01379 | 1,335,082 |
| 2L | 0.04518 | 0.01853 | 1,208,967 |
| 3L | 0.04033 | 0.01201 | 1,137,726 |
| Average | | | 1,227,259 |

Stress-Strain Curve (09-05)_{-40°F}_{05}



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

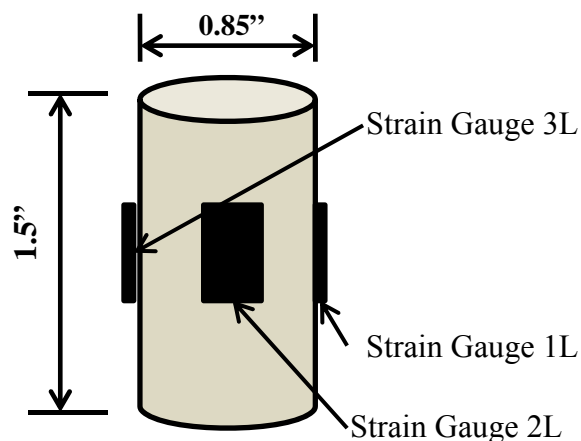
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT5-CZ-70-FY09**
 Material: **Applied Poleramics SC-15, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_z , E_z , ϵ_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **49,710** **lbs**
 Compressive Strength, SC_z : **88,561** **psi**
 Compressive Modulus, E_z : **1,185,088** **psi**
 Ultimate Strain, ϵ_z : **0.079** **in/in**

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT5-CZ-01-70-FY09 | 48,883 | 87,168 | 1,110,642 | 0.0757 | Rupture |
| MAT5-CZ-02-70-FY09 | 49,906 | 88,993 | 1,070,093 | 0.0844 | Rupture |
| MAT5-CZ-03-70-FY09 | 47,893 | 85,000 | 1,322,470 | 0.0655 | Rupture |
| MAT5-CZ-04-70-FY09 | 50,743 | 90,698 | 1,211,138 | 0.1007 | Rupture |
| MAT5-CZ-05-70-FY09 | 51,122 | 90,945 | 1,211,098 | 0.0674 | Rupture |
| Average | 49,710 | 88,561 | 1,185,088 | 0.079 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-80 to H-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-01-70-FY09**
 Test Date: 5/7/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

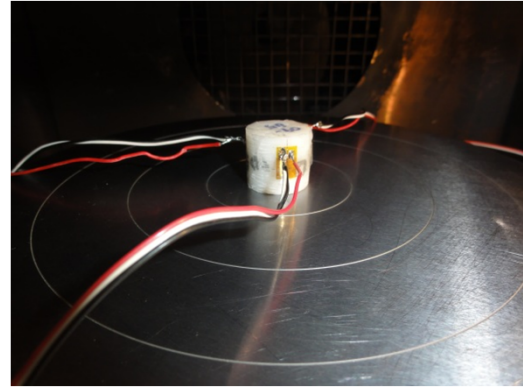
Average Material Properties:

Maximum Load, P_z : 48,883 lbs
 Compressive Strength, SC_z : 87,168 psi
 Compressive Modulus, E_z : 1,110,642 psi
 Ultimate Strain, ϵ_z : 0.076 in/in

Measured Specimen Dimensions:

Thickness, T: 0.740 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,777 lbs
 50% Max Load: 24,442 lbs

PICTURE OF SPECIMEN PRE-TEST



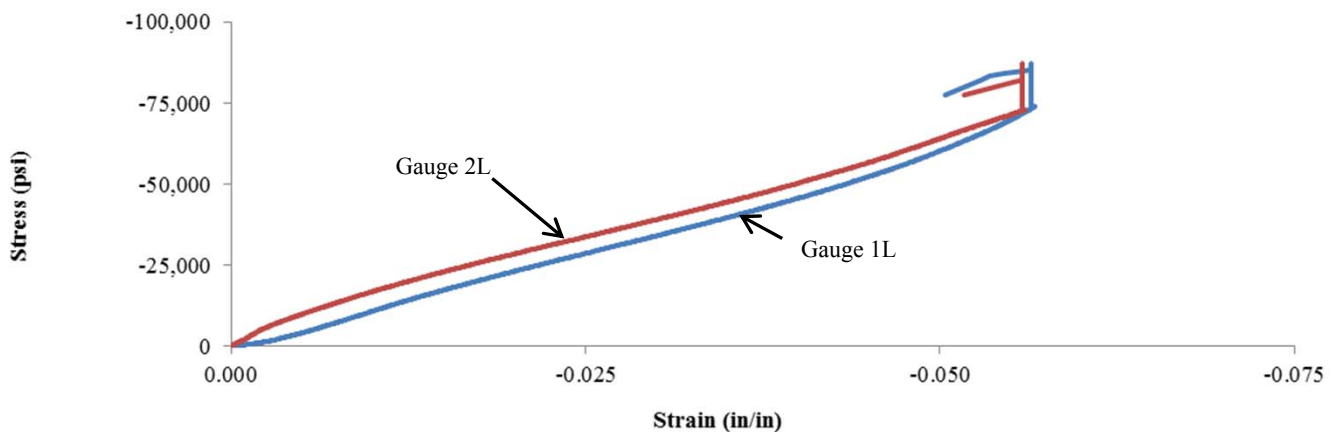
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03828 | 0.01499 | 1,123,240 |
| 2L | 0.03415 | 0.01033 | 1,098,043 |
| 3L | Lost Gauge | | |
| Average | | | 1,110,642 |

Stress-Strain Curve (09-05)_70°F_01



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-02-70-FY09**
 Test Date: 5/7/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

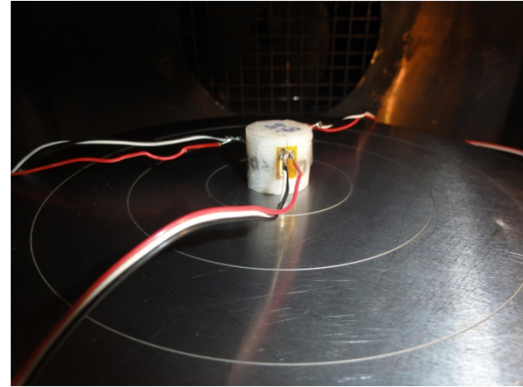
Average Material Properties:

Maximum Load, P_z : 49,906 lbs
 Compressive Strength, SC_z : 88,993 psi
 Compressive Modulus, E_z : 1,070,093 psi
 Ultimate Strain, ϵ_z : 0.084 in/in

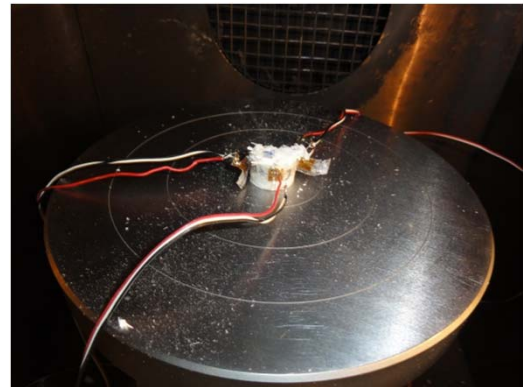
Measured Specimen Dimensions:

Thickness, T: 0.757 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,981 lbs
 50% Max Load: 24,953 lbs

PICTURE OF SPECIMEN PRE-TEST



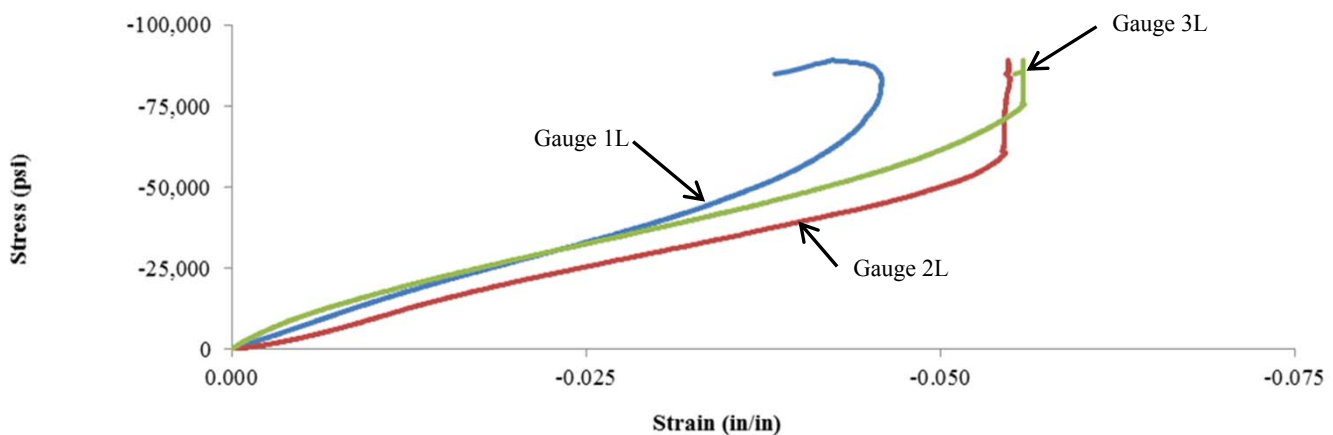
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03364 | 0.01235 | 1,253,956 |
| 2L | 0.04544 | 0.01700 | 938,812 |
| 3L | 0.03700 | 0.01076 | 1,017,510 |
| Average | | | 1,070,093 |

Stress-Strain Curve (09-05)_70°F_02



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-03-70-FY09**
 Test Date: 5/7/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

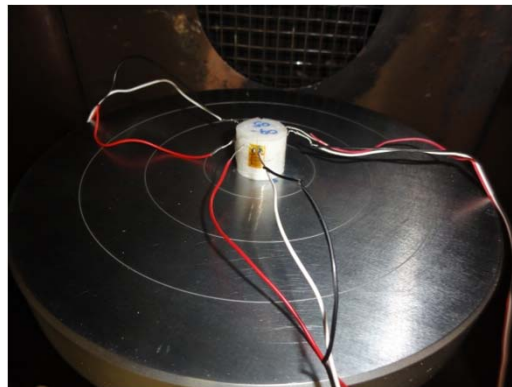
Average Material Properties:

Maximum Load, P_z : 47,893 lbs
 Compressive Strength, SC_z : 85,000 psi
 Compressive Modulus, E_z : 1,322,470 psi
 Ultimate Strain, ϵ_z : 0.066 in/in

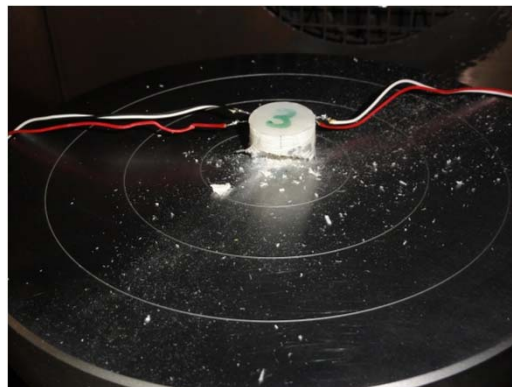
Measured Specimen Dimensions:

Thickness, T: 0.774 in
 Diameter, D: 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,579 lbs
 50% Max Load: 23,947 lbs

PICTURE OF SPECIMEN PRE-TEST



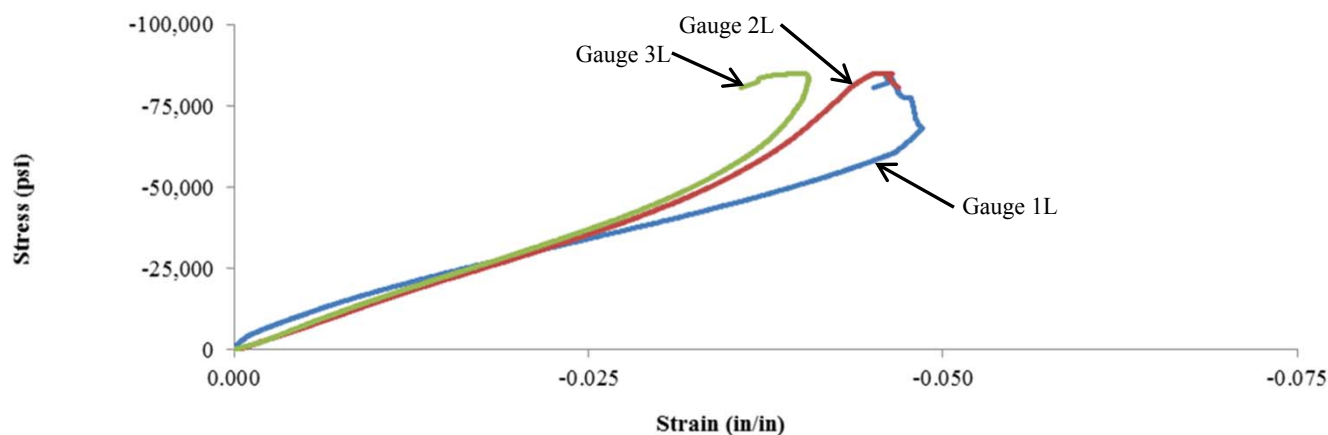
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03300 | 0.00927 | 1,074,760 |
| 2L | 0.02950 | 0.01165 | 1,429,032 |
| 3L | 0.02837 | 0.01095 | 1,463,618 |
| Average | | | 1,322,470 |

Stress-Strain Curve (09-05)_70°F_03



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-04-70-FY09**
 Test Date: 5/8/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

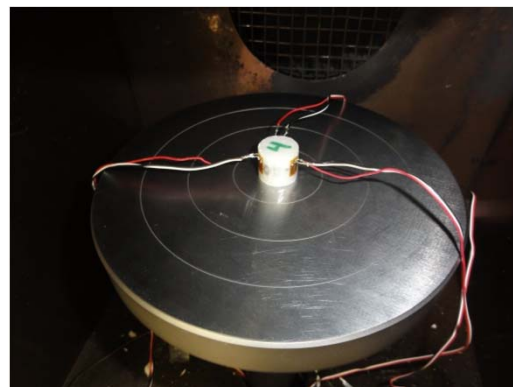
Average Material Properties:

Maximum Load, P_z : 50,743 lbs
 Compressive Strength, SC_z : 90,698 psi
 Compressive Modulus, E_z : 1,211,138 psi
 Ultimate Strain, ϵ_z : 0.101 in/in

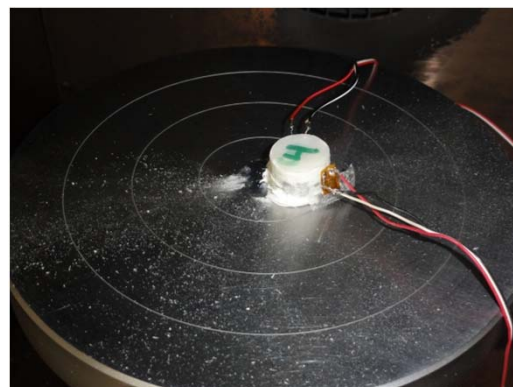
Measured Specimen Dimensions:

Thickness, T: 0.748 in
 Diameter, D: 0.844 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 10,149 lbs
 50% Max Load: 25,371 lbs

PICTURE OF SPECIMEN PRE-TEST



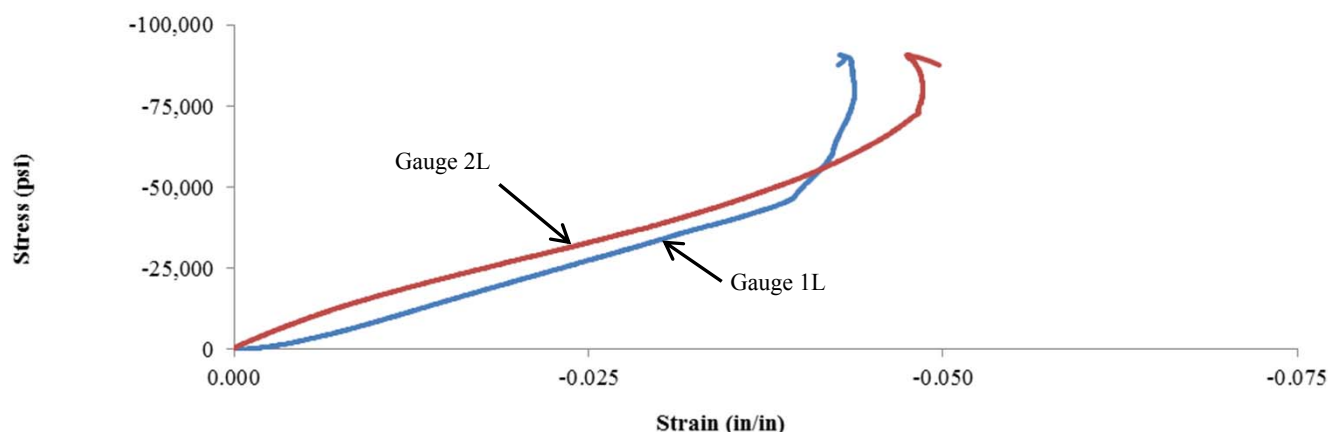
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03884 | 0.01743 | 1,270,523 |
| 2L | 0.03506 | 0.01144 | 1,151,754 |
| 3L | Lost Gauge | | |
| Average | | | 1,211,138 |

Stress-Strain Curve (09-05)_70°F_04



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-05-70-FY09**
 Test Date: 5/8/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

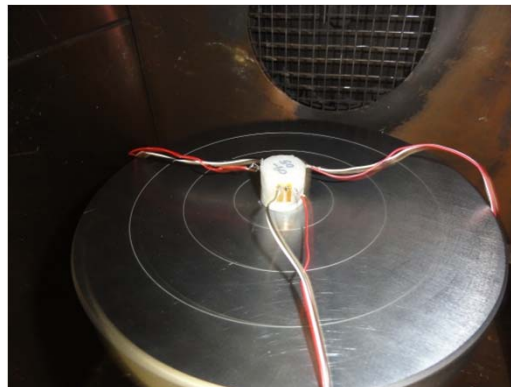
Average Material Properties:

Maximum Load, P_z : 51,122 lbs
 Compressive Strength, SC_z : 90,945 psi
 Compressive Modulus, E_z : 1,211,098 psi
 Ultimate Strain, ϵ_z : 0.067 in/in

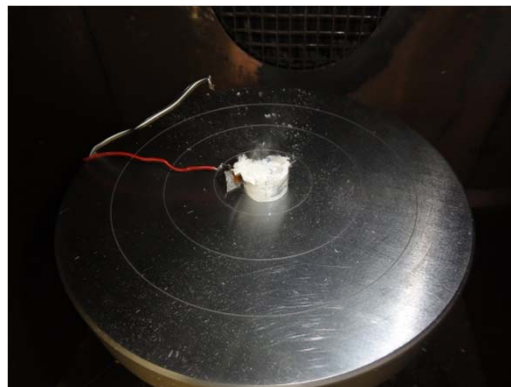
Measured Specimen Dimensions:

Thickness, T: 0.753 in
 Diameter, D: 0.846 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 10,224 lbs
 50% Max Load: 25,561 lbs

PICTURE OF SPECIMEN PRE-TEST



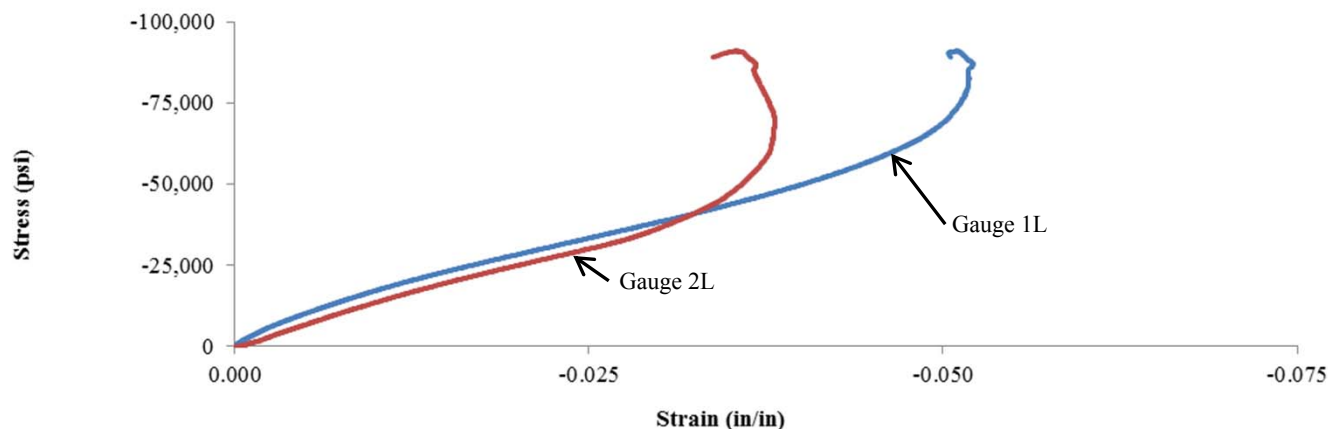
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03059 | 0.00709 | 1,160,947 |
| 2L | 0.03138 | 0.00974 | 1,261,249 |
| 3L | Lost Gauge | | |
| Average | | | 1,211,098 |

Stress-Strain Curve (09-05)_70°F_05



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

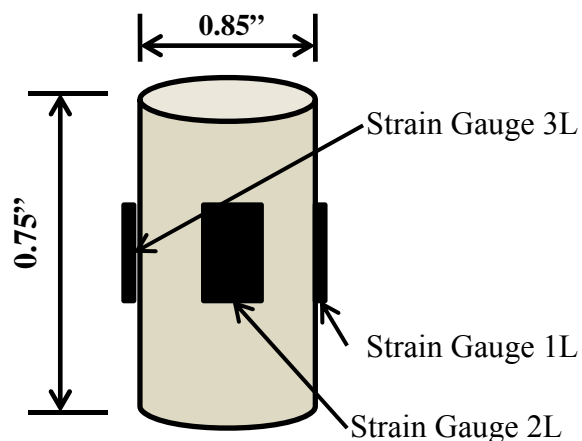
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-CZ-140-FY09
 Material: Applied Poleramics SC-15, S2 Glass
 Nominal Temperature: 140°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 43,718 lbs
 Compressive Strength, SC_z : 77,668 psi
 Compressive Modulus, E_z : 1,160,739 psi
 Ultimate Strain, ϵ_z : 0.069 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT5-CZ-01-140-FY09 | 42,772 | 75,911 | 1,013,992 | 0.0770 | Rupture |
| MAT5-CZ-02-140-FY09 | 45,814 | 81,118 | 1,296,746 | 0.0634 | Rupture |
| MAT5-CZ-03-140-FY09 | 41,518 | 74,210 | 1,087,053 | 0.0694 | Rupture |
| MAT5-CZ-04-140-FY09 | 41,221 | 72,814 | 1,290,240 | 0.0601 | Rupture |
| MAT5-CZ-05-140-FY09 | 47,266 | 84,284 | 1,115,665 | 0.0759 | Rupture |
| Average | 43,718 | 77,668 | 1,160,739 | 0.069 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-86 to H-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “Rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

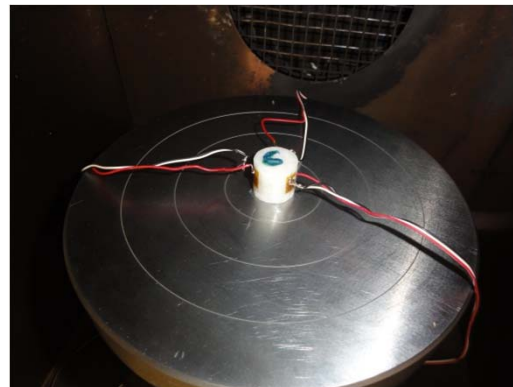
Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

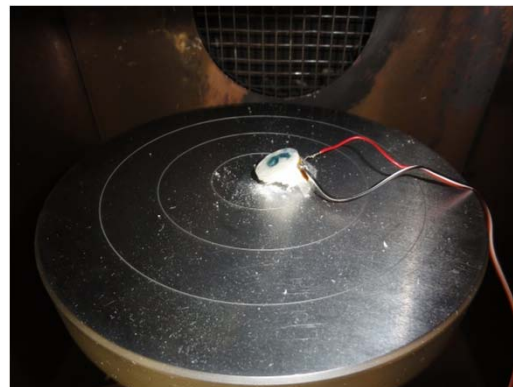
TEST SUMMARY

Specimen ID: **MAT5-CZ-01-140-FY09**
 Test Date: 5/29/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

Maximum Load, P_z : 42,772 lbs
 Compressive Strength, SC_z : 75,911 psi
 Compressive Modulus, E_z : 1,013,992 psi
 Ultimate Strain, ϵ_z : 0.077 in/in

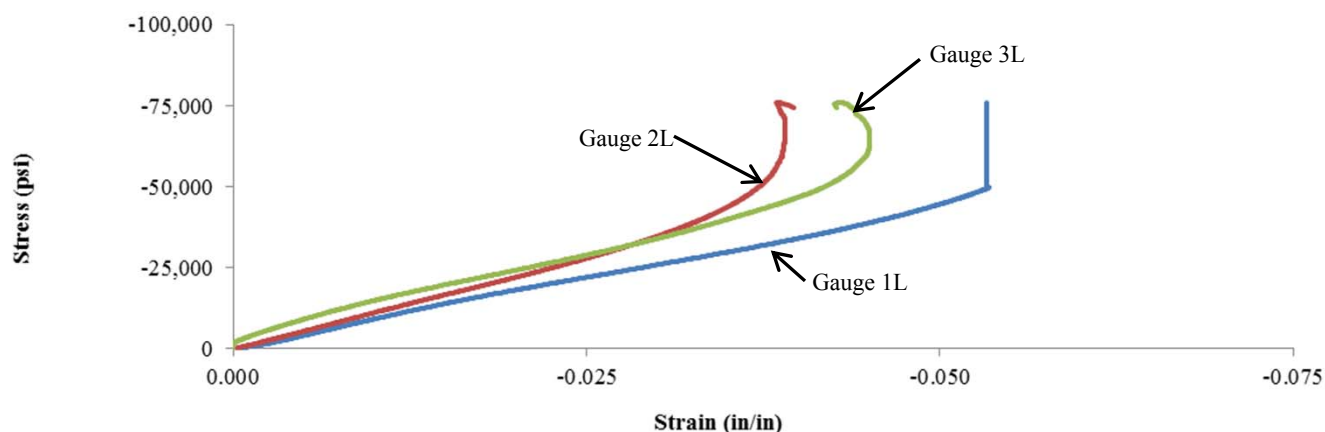
Measured Specimen Dimensions:

Thickness, T : 0.765 in
 Diameter, D : 0.847 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,554 lbs
 50% Max Load: 21,386 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.04411 | 0.01639 | 821,563 |
| 2L | 0.03200 | 0.01359 | 1,236,489 |
| 3L | 0.03338 | 0.01023 | 983,922 |
| Average | | | 1,013,992 |

Stress-Strain Curve (09-05)_140°F_1



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-02-140-FY09**
 Test Date: 5/8/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

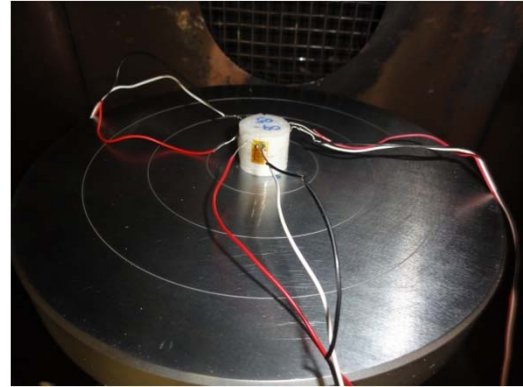
Average Material Properties:

Maximum Load, P_z : 45,814 lbs
 Compressive Strength, SC_z : 81,118 psi
 Compressive Modulus, E_z : 1,296,746 psi
 Ultimate Strain, ϵ_z : 0.063 in/in

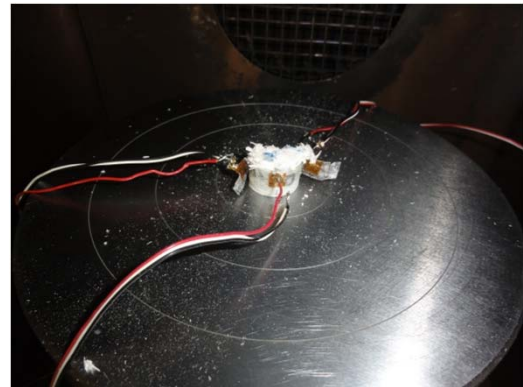
Measured Specimen Dimensions:

Thickness, T: 0.750 in
 Diameter, D: 0.848 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,163 lbs
 50% Max Load: 22,907 lbs

PICTURE OF SPECIMEN PRE-TEST



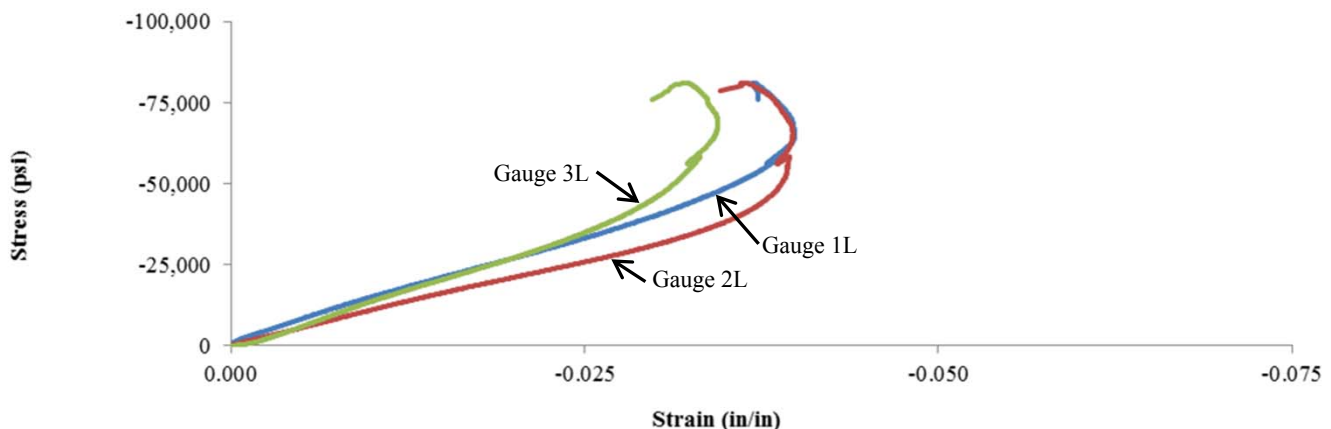
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | 0.03027 | 0.01078 | 1,248,623 |
| 2L | 0.03614 | 0.01480 | 1,140,129 |
| 3L | 0.02791 | 0.01170 | 1,501,486 |
| Average | | | 1,296,746 |

Stress-Strain Curve (09-05)_140°F_2



Engineering Test notes:

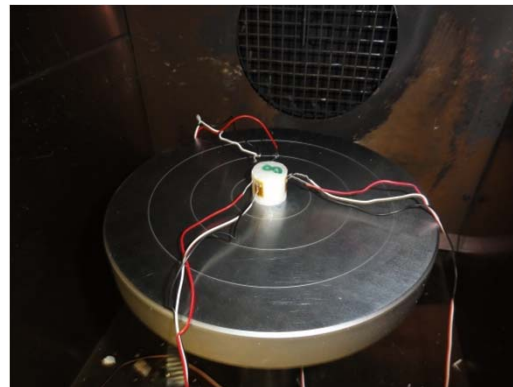
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-03-140-FY09**
 Test Date: 5/8/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

| | | |
|---------------------------------|-----------|-------|
| Maximum Load, P_z : | 41,518 | lbs |
| Compressive Strength, SC_z : | 74,210 | psi |
| Compressive Modulus, E_z : | 1,087,053 | psi |
| Ultimate Strain, ϵ_z : | 0.069 | in/in |

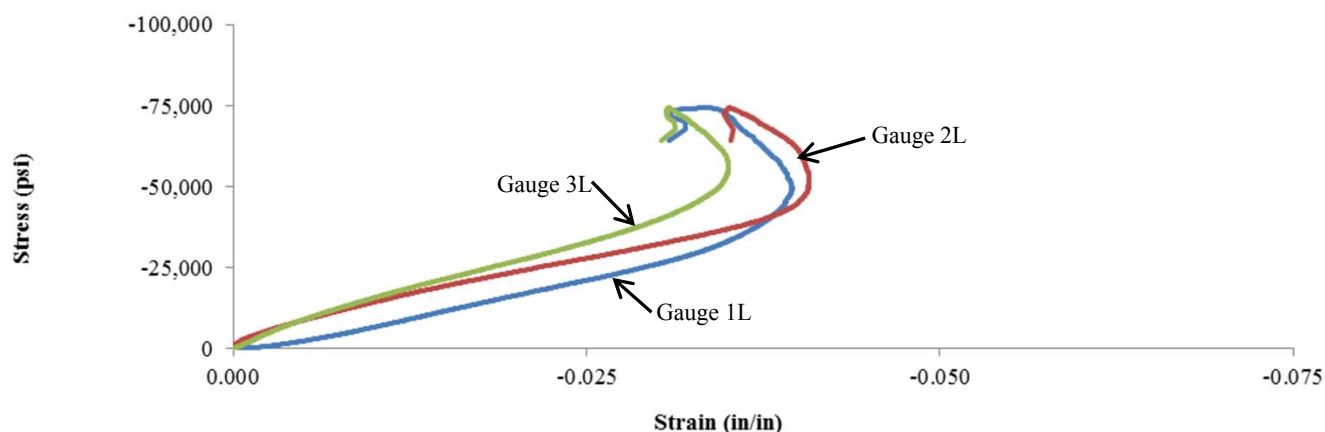
Measured Specimen Dimensions:

| | | |
|-------------------------|---------|-----|
| Thickness, T: | 0.743 | in |
| Diameter, D: | 0.844 | in |
| Laboratory Temperature: | 70°F | |
| Failure Mode: | Rupture | |
| 20% Max Load: | 8,304 | lbs |
| 50% Max Load: | 20,759 | lbs |

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03678 | 0.01822 | 1,199,357 |
| 2L | 0.03512 | 0.01029 | 896,541 |
| 3L | 0.02828 | 0.00918 | 1,165,260 |
| Average | | | 1,087,053 |

Stress-Strain Curve (09-05)_140°F_3



Engineering Test notes:

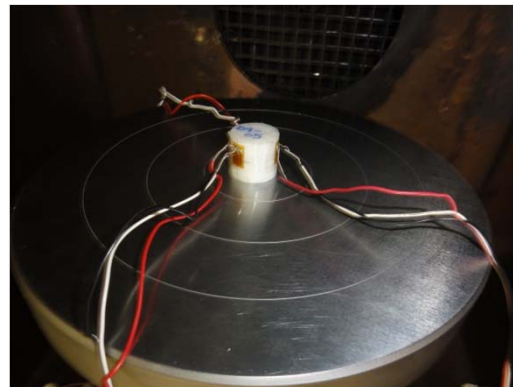
- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

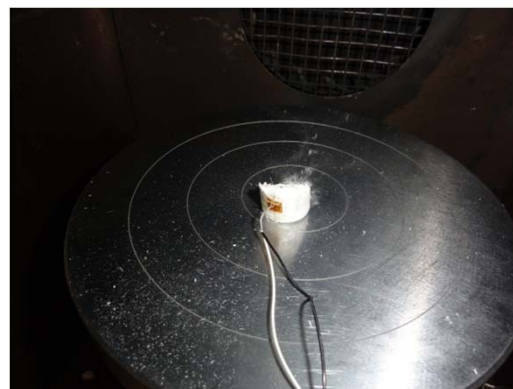
TEST SUMMARY

Specimen ID: **MAT5-CZ-04-140-FY09**
 Test Date: 5/8/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

PICTURE OF SPECIMEN PRE-TEST



PICTURE OF SPECIMEN POST-TEST



Average Material Properties:

Maximum Load, P_z : 41,221 lbs
 Compressive Strength, SC_z : 72,814 psi
 Compressive Modulus, E_z : 1,290,240 psi
 Ultimate Strain, ϵ_z : 0.060 in/in

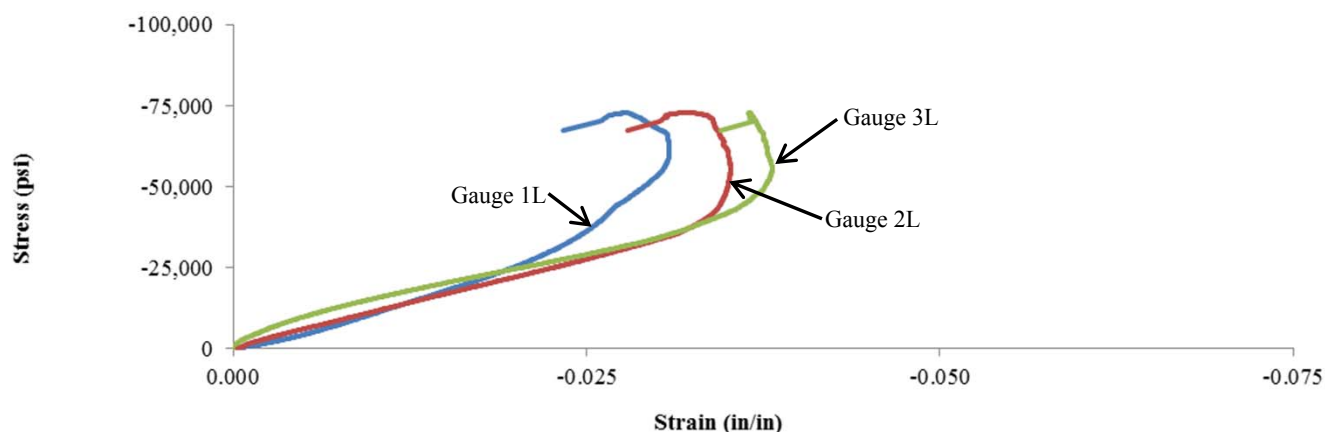
Measured Specimen Dimensions:

Thickness, T : 0.770 in
 Diameter, D : 0.849 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 8,244 lbs
 50% Max Load: 20,611 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.02501 | 0.01260 | 1,760,359 |
| 2L | 0.03183 | 0.01275 | 1,144,514 |
| 3L | 0.03165 | 0.00903 | 965,847 |
| Average | | | 1,290,240 |

Stress-Strain Curve (09-05)_140°F_4



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-CZ-05-140-FY09**
 Test Date: 5/9/12
 Specimen Received: 10/31/11
 Properties Measured: SC_z , E_z , ϵ_z

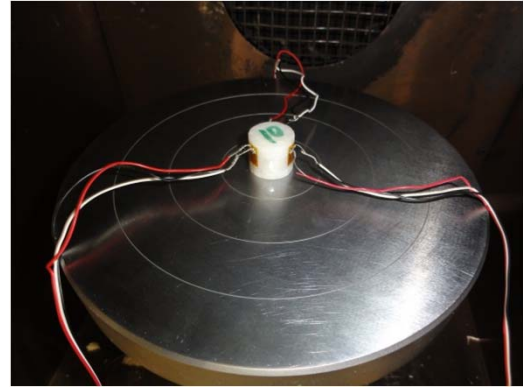
Average Material Properties:

Maximum Load, P_z : 47,266 lbs
 Compressive Strength, SC_z : 84,284 psi
 Compressive Modulus, E_z : 1,115,665 psi
 Ultimate Strain, ϵ_z : 0.076 in/in

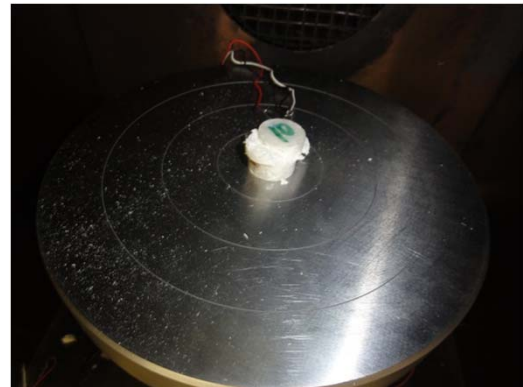
Measured Specimen Dimensions:

Thickness, T: 0.743 in
 Diameter, D: 0.845 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 9,453 lbs
 50% Max Load: 23,633 lbs

PICTURE OF SPECIMEN PRE-TEST



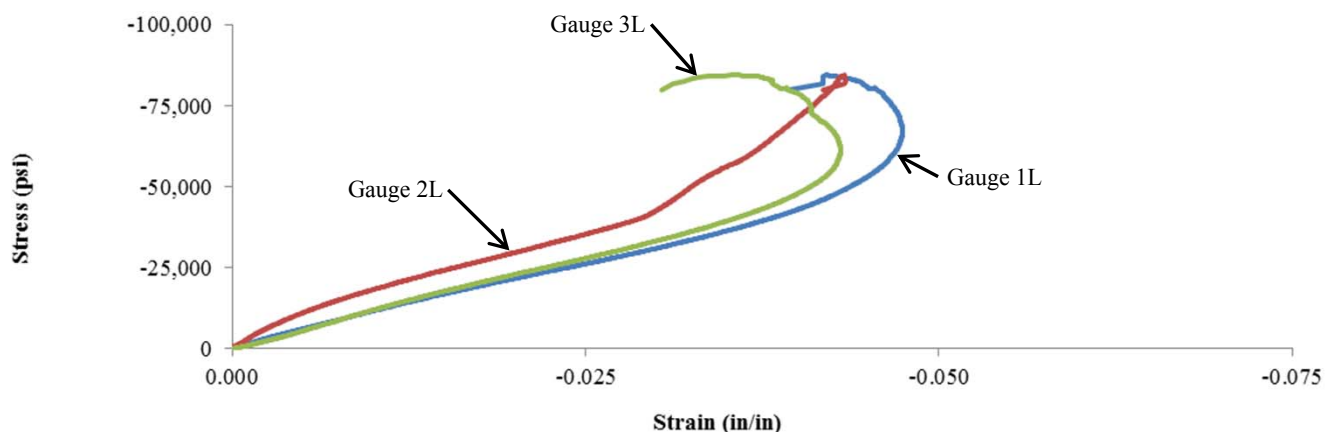
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | 0.03945 | 0.01485 | 1,028,238 |
| 2L | 0.02980 | 0.00882 | 1,205,421 |
| 3L | 0.03684 | 0.01413 | 1,113,338 |
| Average | | | 1,115,665 |

Stress-Strain Curve (09-05)_140°F_5



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXZ-N40-FY09

Material: SC-15, S2 Glass

Nominal Temperature: -40°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 757 lbs

Shear Strength, S_{xz} : 4,853 psi

Shear Modulus, G_{xz} : 469,174 psi

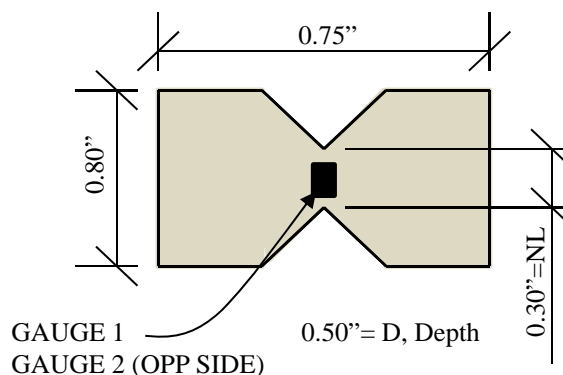
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|-------------------------------|--------------------------------|-------------------------------|--------------|
| MAT5-SXZ-01-N40-FY09 | 806 | 4,950 | 449,342 | Shear |
| MAT5-SXZ-02-N40-FY09 | 743 | 4,985 | 472,975 | Shear |
| MAT5-SXZ-03-N40-FY09 | 682 | 4,468 | 462,681 | Shear |
| MAT5-SXZ-04-N40-FY09 | 733 | 4,874 | 461,933 | Shear |
| MAT5-SXZ-05-N40-FY09 | 820 | 4,991 | 498,939 | Shear |
| Average | 757 | 4,853 | 469,174 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets H-92 to H-96
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration**

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-01-N40-FY09
 Test Date: 4/13/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 806 lbs
 Shear Strength, S_{xz} : 4,950 psi
 Shear Modulus, G_{xz} : 449,342 psi

Measured Specimen Dimensions:

Depth, D: 0.492 in
 Notch Length, NL: 0.331 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 403 lbs
 20% Max Load: 161 lbs

PICTURE OF SPECIMEN PRE-TEST



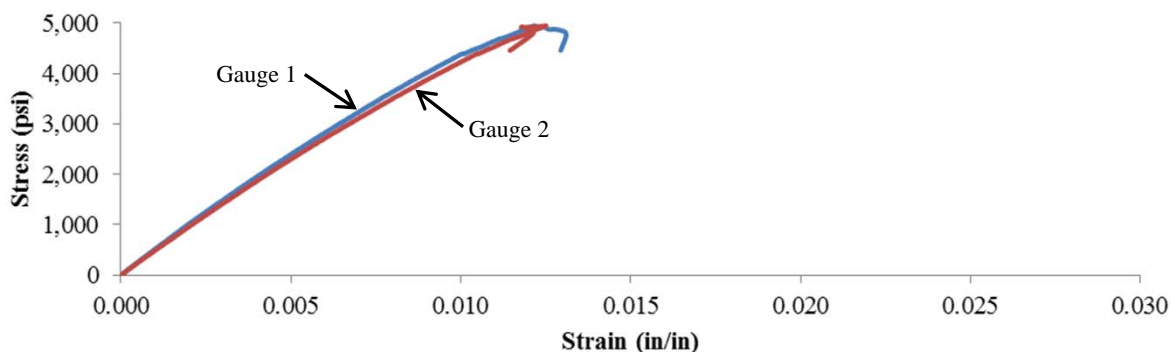
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0019 | 457,394 |
| 2 | 0.0054 | 0.0020 | 441,290 |
| Average | | | 449,342 |

Stress-Strain Curve -40°F_01_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT5-SXZ-02-N40-FY09**
 Test Date: 4/13/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **743** **lbs**
Shear Strength, S_{xz} : **4,985** **psi**
Shear Modulus, G_{xz} : **472,975** **psi**

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.301 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 371 lbs
 20% Max Load: 149 lbs

PICTURE OF SPECIMEN PRE-TEST



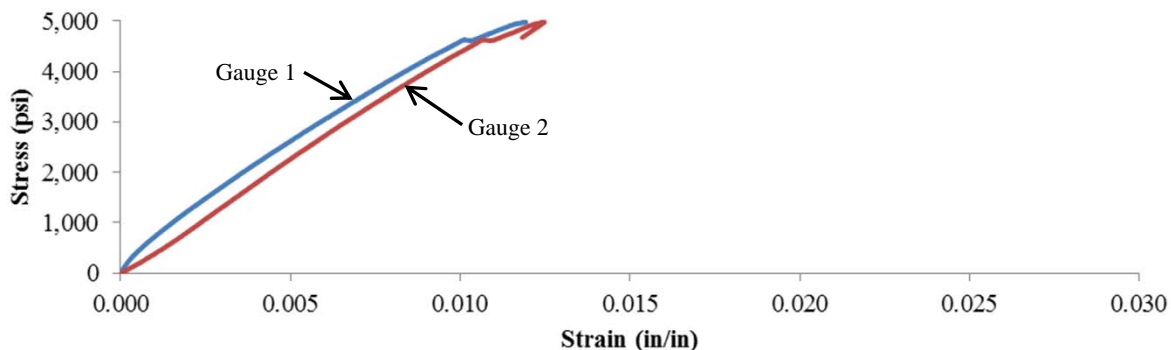
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0047 | 0.0015 | 470,356 |
| 2 | 0.0055 | 0.0024 | 475,593 |
| Average | | | 472,975 |

Stress-Strain Curve -40°F_02_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT5-SXZ-03-N40-FY09**
 Test Date: 4/17/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **682** **lbs**
Shear Strength, S_{xz} : **4,468** **psi**
Shear Modulus, G_{xz} : **462,681** **psi**

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, NL: 0.309 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 341 lbs
 20% Max Load: 136 lbs

PICTURE OF SPECIMEN PRE-TEST



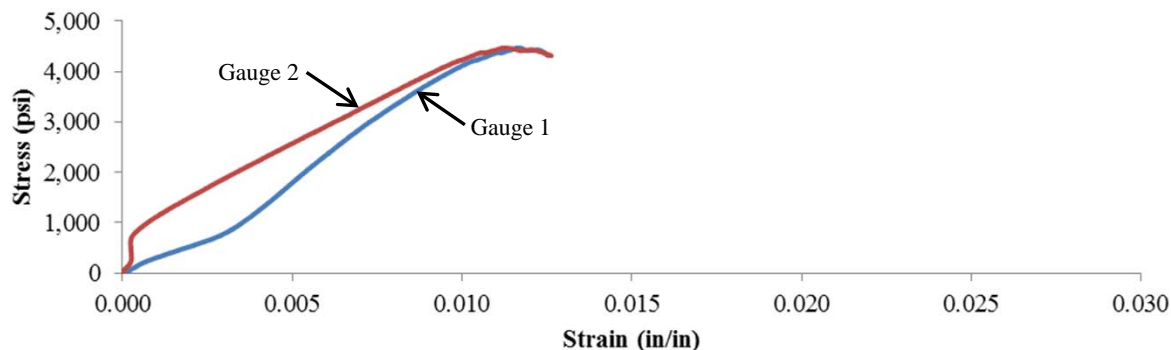
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0058 | 0.0033 | 539,353 |
| 2 | 0.0040 | 0.0005 | 386,009 |
| Average | | | 462,681 |

Stress-Strain Curve -40°F_03_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT5-SXZ-04-N40-FY09**
 Test Date: 4/17/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

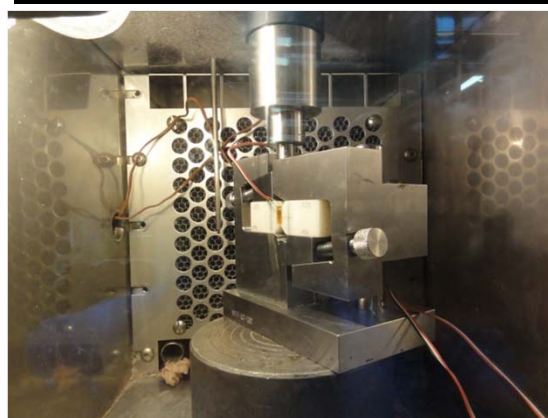
Average Material Properties:

Ultimate Load, P_{max} : 733 lbs
Shear Strength, S_{xz} : 4,874 psi
Shear Modulus, G_{xz} : 461,933 psi

Measured Specimen Dimensions:

Depth, D: 0.493 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 366 lbs
 20% Max Load: 147 lbs

PICTURE OF SPECIMEN PRE-TEST



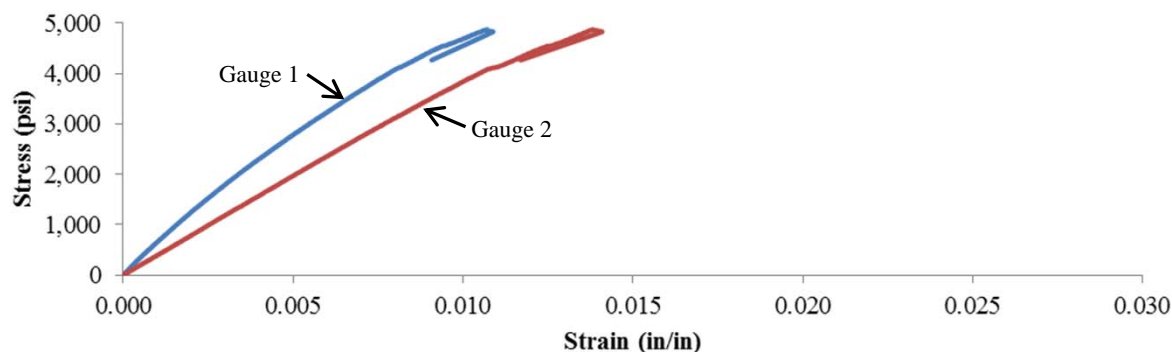
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0043 | 0.0015 | 532,493 |
| 2 | 0.0062 | 0.0025 | 391,373 |
| Average | | | 461,933 |

Stress-Strain Curve -40°F_04_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT5-SXZ-05-N40-FY09**
 Test Date: 4/17/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **820** **lbs**
Shear Strength, S_{xz} : **4,991** **psi**
Shear Modulus, G_{xz} : **498,939** **psi**

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.332 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 410 lbs
 20% Max Load: 164 lbs

PICTURE OF SPECIMEN PRE-TEST



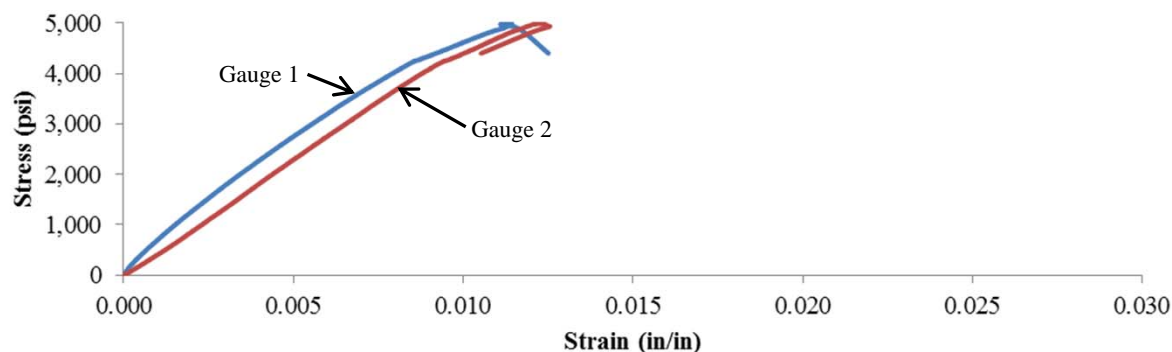
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0044 | 0.0015 | 515,634 |
| 2 | 0.0054 | 0.0023 | 482,243 |
| Average | | | 498,939 |

Stress-Strain Curve -40°F_05_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXZ-70-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 70°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 666 lbs

Shear Strength, S_{xz} : 4,215 psi

Shear Modulus, G_{xz} : 340,799 psi

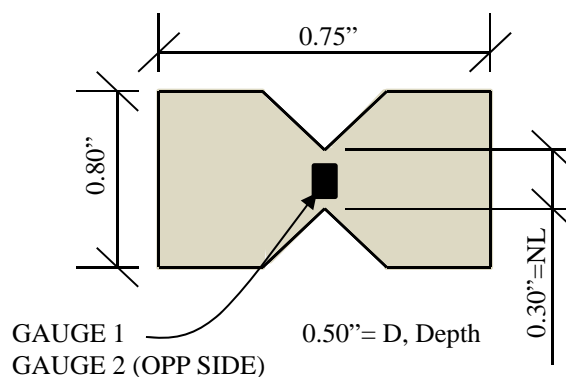
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT5-SXZ-01-70-FY09 | 632 | 4,124 | 362,776 | Shear |
| MAT5-SXZ-02-70-FY09 | 694 | 4,009 | 329,033 | Shear |
| MAT5-SXZ-03-70-FY09 | 635 | 4,174 | 304,714 | Shear |
| MAT5-SXZ-04-70-FY09 | 720 | 4,414 | 348,853 | Shear |
| MAT5-SXZ-05-70-FY09 | 650 | 4,351 | 358,621 | Shear |
| Average | 666 | 4,215 | 340,799 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets H-98 to H-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration**

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-01-70-FY09
 Test Date: 10/7/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

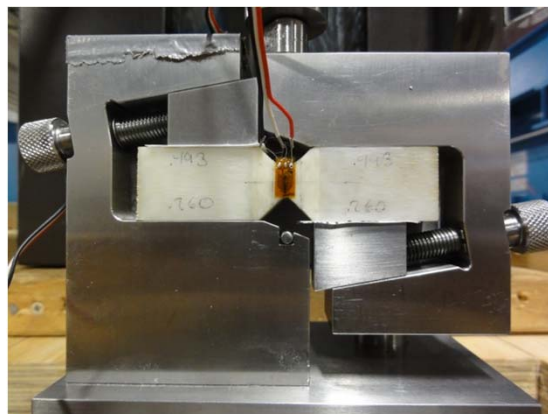
Average Material Properties:

Ultimate Load, P_{max} : 632 lbs
 Shear Strength, S_{xz} : 4,124 psi
 Shear Modulus, G_{xz} : 362,776 psi

Measured Specimen Dimensions:

Depth, D: 0.493 in
 Notch Length, NL: 0.311 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 316 lbs
 20% Max Load: 126 lbs

PICTURE OF SPECIMEN PRE-TEST



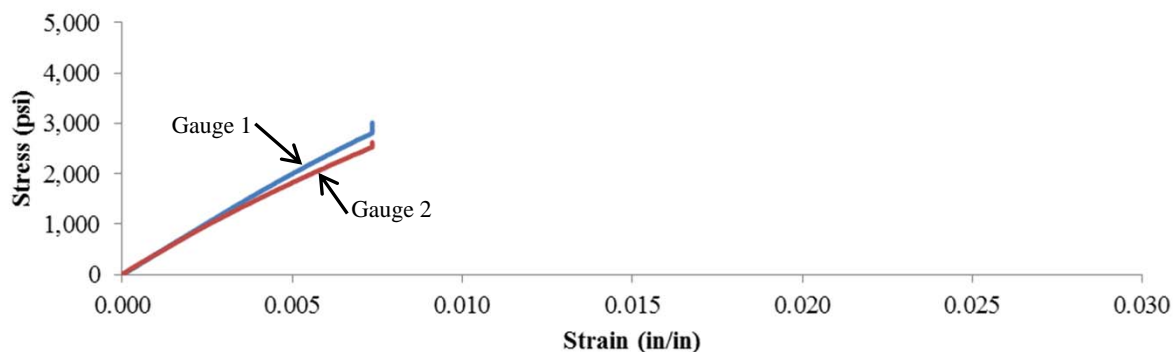
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0020 | 390,961 |
| 2 | 0.0058 | 0.0021 | 334,591 |
| Average | | | 362,776 |

Stress-Strain Curve 70°F_01_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-02-70-FY09
 Test Date: 10/7/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

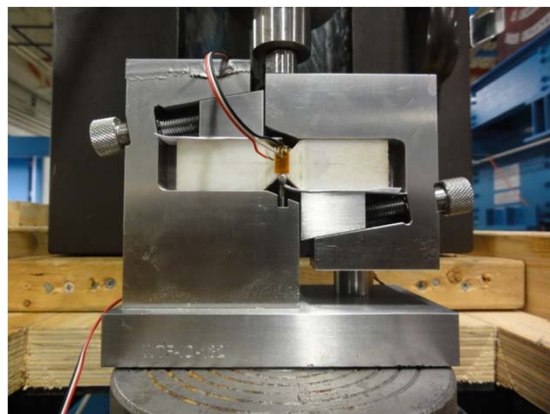
Average Material Properties:

Ultimate Load, P_{max} : 694 lbs
 Shear Strength, S_{xz} : 4,009 psi
 Shear Modulus, G_{xz} : 329,033 psi

Measured Specimen Dimensions:

Depth, D: 0.493 in
 Notch Length, NL: 0.351 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 347 lbs
 20% Max Load: 139 lbs

PICTURE OF SPECIMEN PRE-TEST



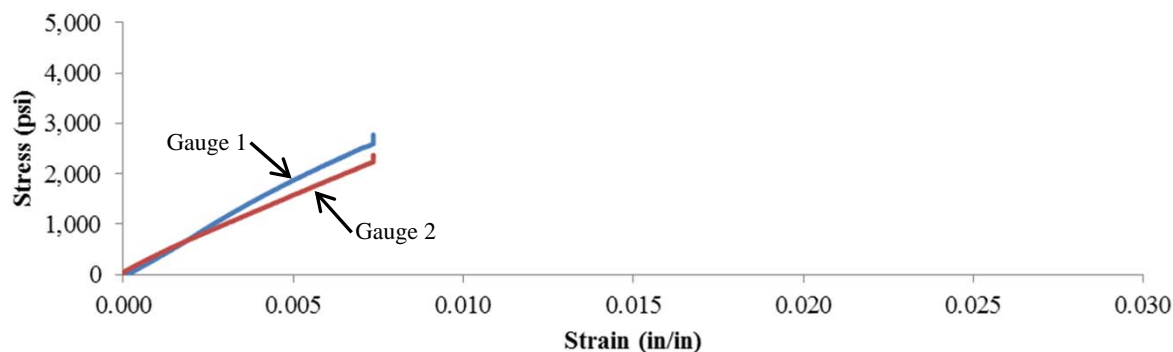
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0054 | 0.0022 | 371,777 |
| 2 | 0.0065 | 0.0023 | 286,289 |
| Average | | | 329,033 |

Stress-Strain Curve 70°F_02_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-03-70-FY09
 Test Date: 10/10/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

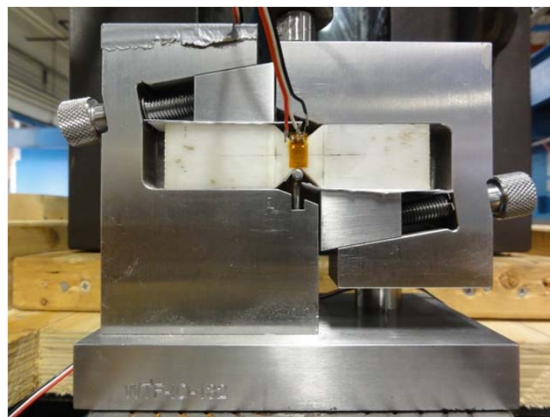
Average Material Properties:

Ultimate Load, P_{max} : 635 lbs
 Shear Strength, S_{xz} : 4,174 psi
 Shear Modulus, G_{xz} : 304,714 psi

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, NL: 0.308 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 318 lbs
 20% Max Load: 127 lbs

PICTURE OF SPECIMEN PRE-TEST



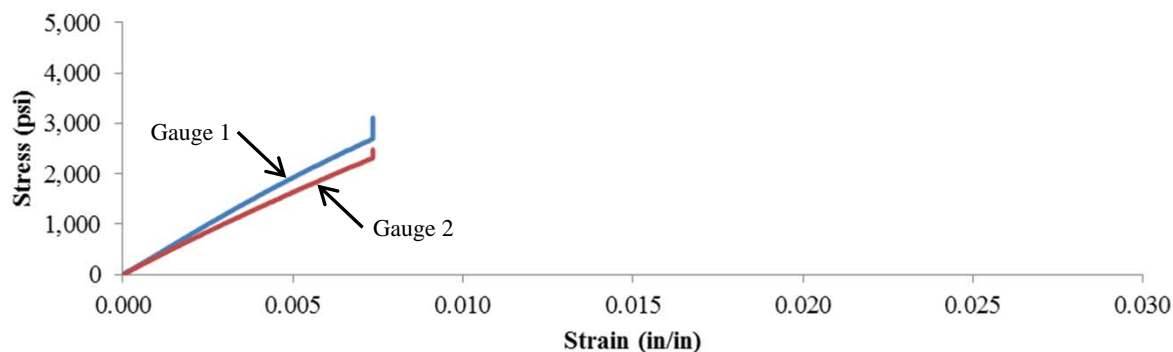
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0060 | 0.0023 | 333,375 |
| 2 | 0.0072 | 0.0027 | 276,053 |
| Average | | | 304,714 |

Stress-Strain Curve 70°F_03_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-04-70-FY09
 Test Date: 10/10/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

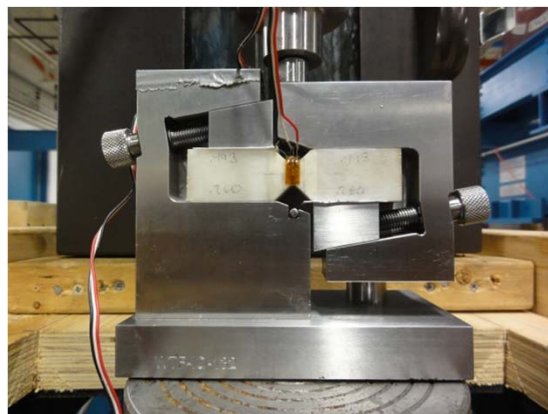
Average Material Properties:

Ultimate Load, P_{max} : 720 lbs
 Shear Strength, S_{xz} : 4,414 psi
 Shear Modulus, G_{xz} : 348,853 psi

Measured Specimen Dimensions:

Depth, D: 0.493 in
 Notch Length, NL: 0.331 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 360 lbs
 20% Max Load: 144 lbs

PICTURE OF SPECIMEN PRE-TEST



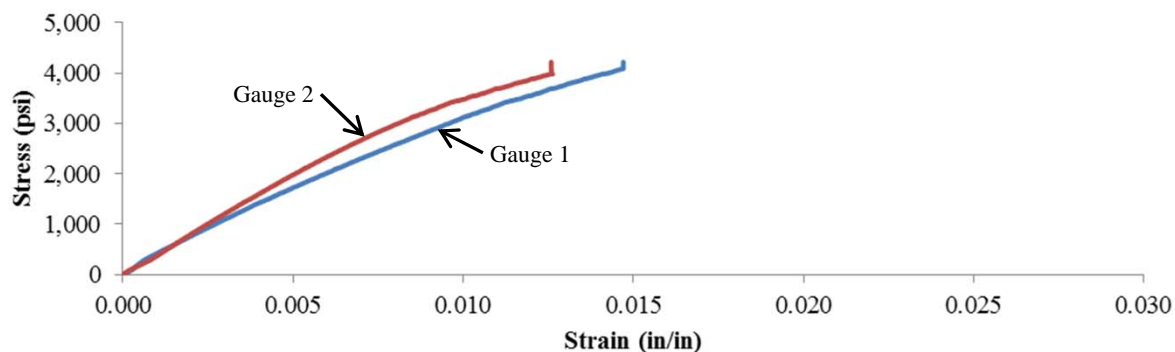
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0066 | 0.0024 | 309,734 |
| 2 | 0.0056 | 0.0022 | 387,972 |
| Average | | | 348,853 |

Stress-Strain Curve 70°F_04_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-05-70-FY09
 Test Date: 10/11/11
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

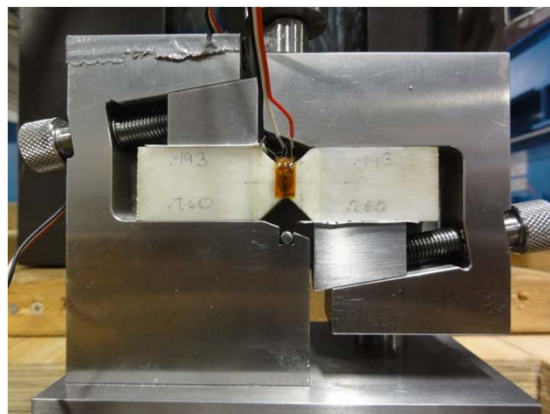
Average Material Properties:

Ultimate Load, P_{max} : 650 lbs
 Shear Strength, S_{xz} : 4,351 psi
 Shear Modulus, G_{xz} : 358,621 psi

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.302 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 325 lbs
 20% Max Load: 130 lbs

PICTURE OF SPECIMEN PRE-TEST



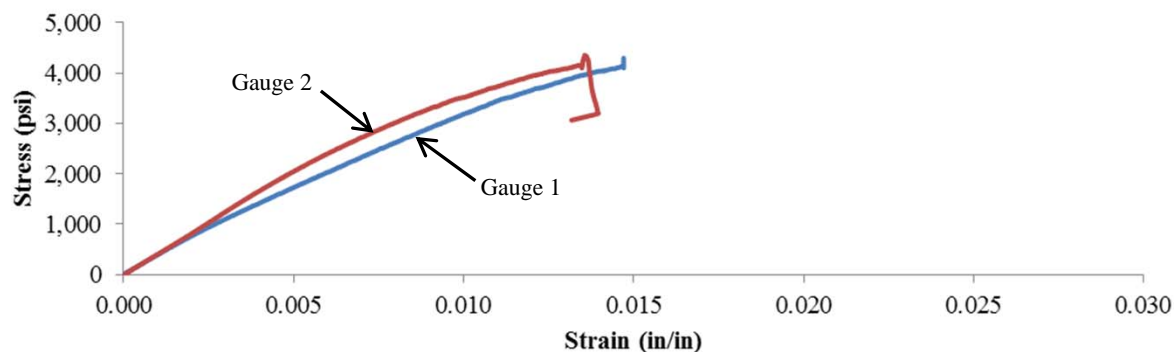
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0065 | 0.0023 | 311,624 |
| 2 | 0.0053 | 0.0021 | 405,619 |
| Average | | | 358,621 |

Stress-Strain Curve 70°F_05_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-SXZ-140-FY09

Material: SC-15, S2 Glass

Nominal Temperature: 140°F

Properties Measured: G_{xz} , S_{xz}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 560 lbs

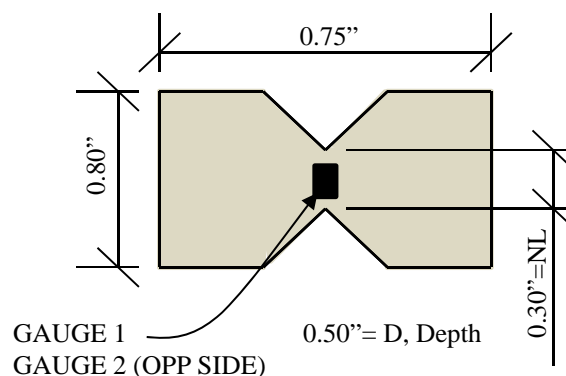
Shear Strength, S_{xz} : 3,666 psi

Shear Modulus, G_{xz} : 306,779 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT5-SXZ-01-140-FY09 | 547 | 3,755 | 284,274 | Shear |
| MAT5-SXZ-02-140-FY09 | 562 | 3,807 | 306,358 | Shear |
| MAT5-SXZ-03-140-FY09 | 579 | 3,575 | 302,982 | Shear |
| MAT5-SXZ-04-140-FY09 | 603 | 3,780 | 282,670 | Shear |
| MAT5-SXZ-05-140-FY09 | 507 | 3,416 | 357,613 | Shear |
| Average | 560 | 3,666 | 306,779 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets H-104 to H-108
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

FACING RESEARCHERS

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-01-140-FY09
 Test Date: 3/21/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 547 lbs
 Shear Strength, S_{xz} : 3,755 psi
 Shear Modulus, G_{xz} : 284,274 psi

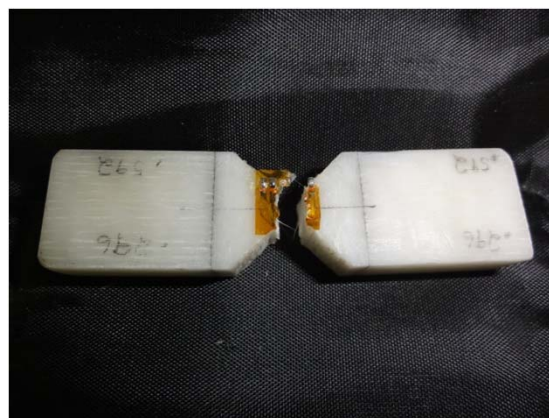
Measured Specimen Dimensions:

Depth, D: 0.492 in
 Notch Length, NL: 0.296 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 273 lbs
 20% Max Load: 109 lbs

PICTURE OF SPECIMEN PRE-TEST



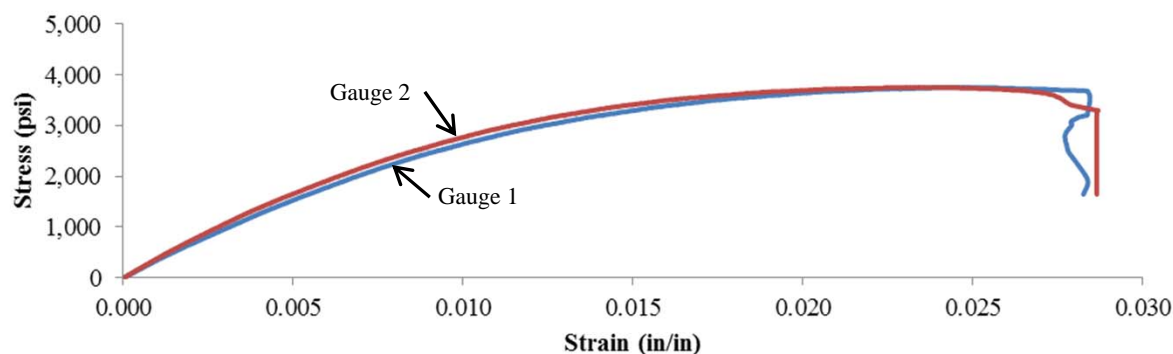
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0064 | 0.0023 | 274,177 |
| 2 | 0.0059 | 0.0020 | 294,372 |
| Average | | | 284,274 |

Stress-Strain Curve 140°F_01_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-02-140-FY09
 Test Date: 3/22/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 562 lbs
 Shear Strength, S_{xz} : 3,807 psi
 Shear Modulus, G_{xz} : 306,358 psi

Measured Specimen Dimensions:

Depth, D: 0.494 in
 Notch Length, NL: 0.299 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 281 lbs
 20% Max Load: 112 lbs

PICTURE OF SPECIMEN PRE-TEST



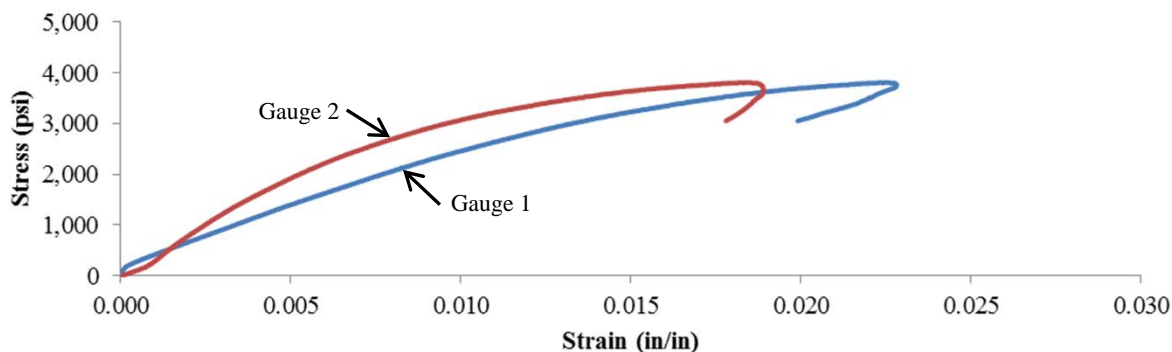
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0072 | 0.0024 | 234,149 |
| 2 | 0.0049 | 0.0019 | 378,567 |
| Average | | | 306,358 |

Stress-Strain Curve 140°F_02_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-03-140-FY09
 Test Date: 3/23/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 579 lbs
 Shear Strength, S_{xz} : 3,575 psi
 Shear Modulus, G_{xz} : 302,982 psi

Measured Specimen Dimensions:

Depth, D: 0.488 in
 Notch Length, NL: 0.332 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 290 lbs
 20% Max Load: 116 lbs

PICTURE OF SPECIMEN PRE-TEST



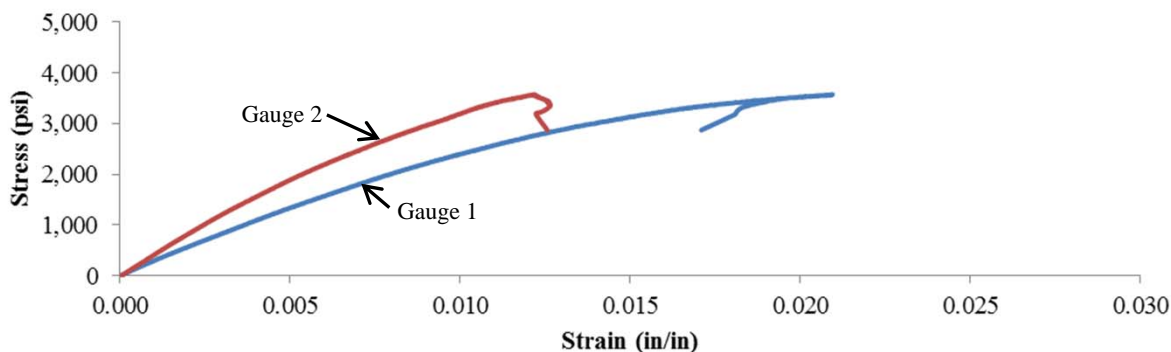
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0069 | 0.0025 | 243,553 |
| 2 | 0.0047 | 0.0017 | 362,411 |
| Average | | | 302,982 |

Stress-Strain Curve 140°F_03_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT5-SXZ-04-140-FY09
 Test Date: 3/23/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 603 lbs
 Shear Strength, S_{xz} : 3,780 psi
 Shear Modulus, G_{xz} : 282,670 psi

Measured Specimen Dimensions:

Depth, D: 0.491 in
 Notch Length, NL: 0.325 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 302 lbs
 20% Max Load: 121 lbs

PICTURE OF SPECIMEN PRE-TEST



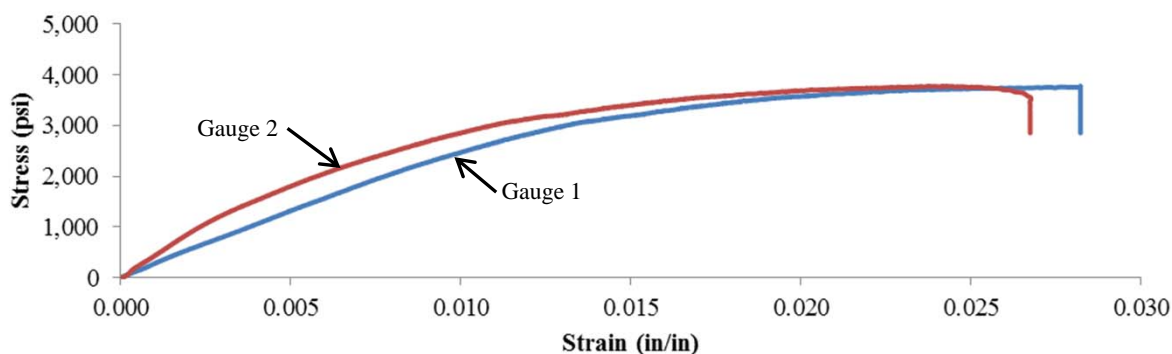
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0073 | 0.0028 | 251,859 |
| 2 | 0.0053 | 0.0017 | 313,480 |
| Average | | | 282,670 |

Stress-Strain Curve 140°F_04_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT5-SXZ-05-140-FY09**
 Test Date: 4/11/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : **507** **lbs**
Shear Strength, S_{xz} : **3,416** **psi**
Shear Modulus, G_{xz} : **357,613** **psi**

Measured Specimen Dimensions:

Depth, D: 0.495 in
 Notch Length, NL: 0.300 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 254 lbs
 20% Max Load: 101 lbs

PICTURE OF SPECIMEN PRE-TEST



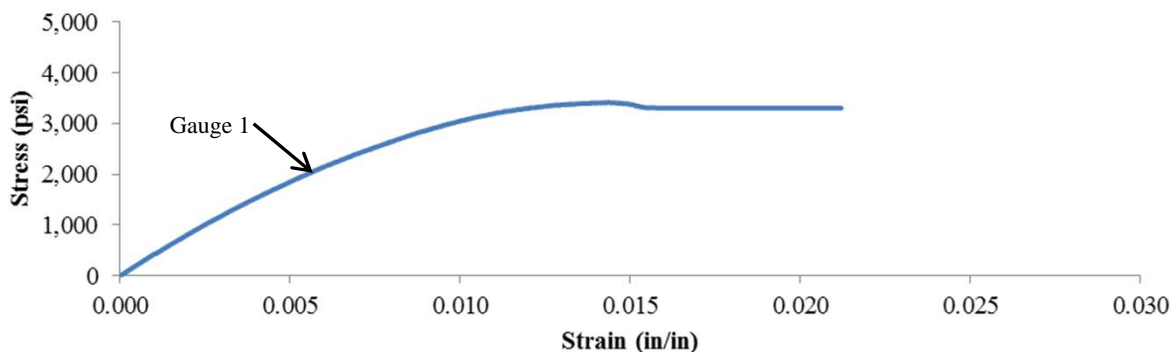
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0045 | 0.0017 | 357,613 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 357,613 |

Stress-Strain Curve 140°F_05_(09-05)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

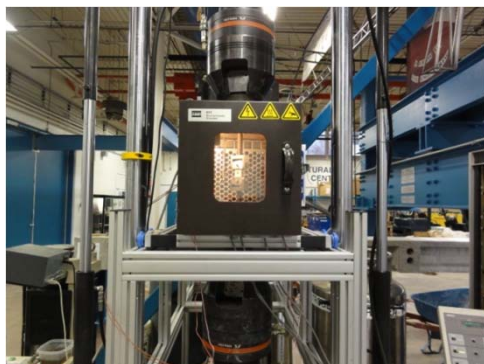
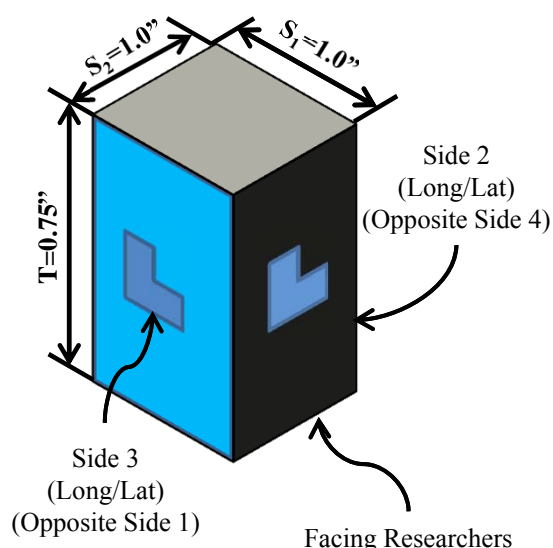
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT5-OP-N40-FY09
 Material: Applied Poleramics SC-15, S2 Glass
 Nominal Temperature: -40°F
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : 0.1297
 Maximum Load, P_z : 4,473 lbs

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT5-OP-1-N40-FY09 | 4,476 | 0.1584 | Rupture |
| 2 | MAT5-OP-2-N40-FY09 | 4,476 | 0.0980 | Rupture |
| 3 | MAT5-OP-3-N40-FY09 | 4,463 | 0.1488 | Bondline |
| 4 | MAT5-OP-4-N40-FY09 | 4,472 | 0.1252 | Rupture |
| 5 | MAT5-OP-5-N40-FY09 | 4,480 | 0.1180 | Rupture |
| Average | | 4,473 | 0.1297 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

-40°F Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-110 thru H-114 for individual specimen data.
- 2) 6 specimens tested, group of 5 specimens with representative data to report.
- 3) Max Load is based on MAT5-TZ-N40-FY09 strength data.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 5) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-1-N40-FY09**
 Test Date: 3/30/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,476 lbs
 Poisson's Ratio, v_{xz} : 0.1584

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 0.998 in

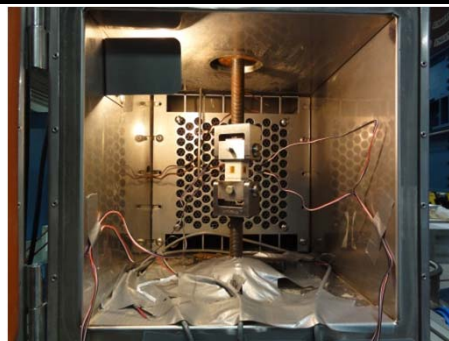
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,238 lbs

20% Max Load: 895 lbs

PICTURE OF SPECIMEN PRE-TEST



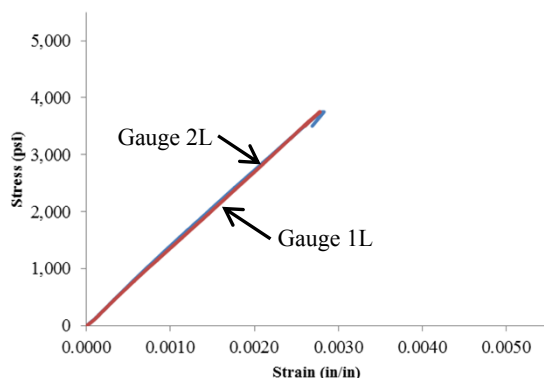
PICTURE OF SPECIMEN POST-TEST



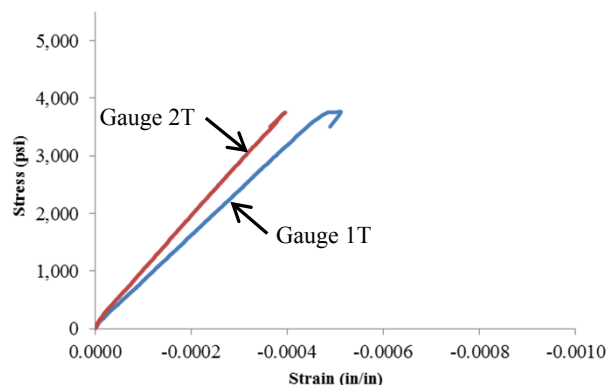
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001626 | 0.000635 | 1T | -0.000279 | -0.000107 | 0.1736 |
| 2L | 0.001659 | 0.000652 | 2T | -0.000230 | -0.000086 | 0.1432 |
| Average | | | | | | 0.1584 |

Stress-Strain Curve_-40°F_1_(09-05)_Long



Stress-Strain Curve_-40°F_1_(09-05)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-2-N40-FY09**
 Test Date: 3/30/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,476 lbs
 Poisson's Ratio, v_{xz} : 0.0980

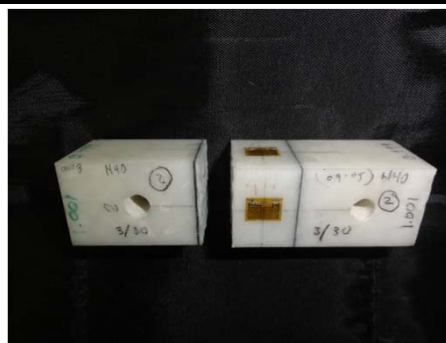
Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,238 lbs
 20% Max Load: 895 lbs

PICTURE OF SPECIMEN PRE-TEST



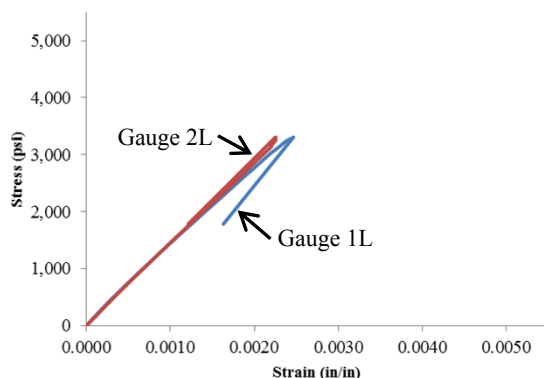
PICTURE OF SPECIMEN POST-TEST



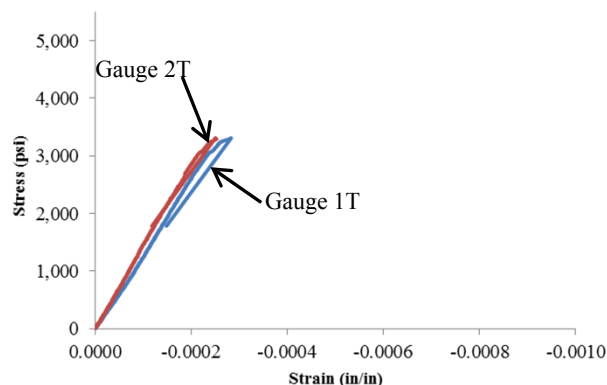
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001596 | 0.000598 | 1T | -0.000172 | -0.000074 | 0.0985 |
| 2L | 0.001565 | 0.000606 | 2T | -0.000156 | -0.000063 | 0.0975 |
| Average | | | | | | 0.0980 |

Stress-Strain Curve_-40°F_2_(09-05)_Long



Stress-Strain Curve_-40°F_2_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-140-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-3-N40-FY09**
 Test Date: 3/30/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,463 lbs
 Poisson's Ratio, v_{xz} : 0.1488

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.998 in

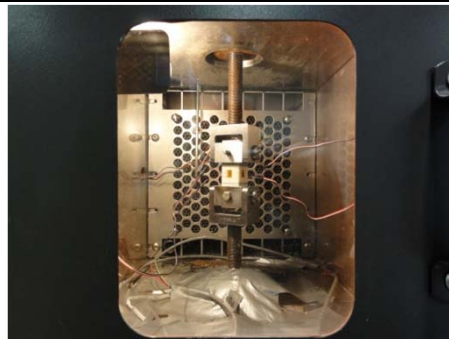
Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 2,231 lbs

20% Max Load: 893 lbs

PICTURE OF SPECIMEN PRE-TEST



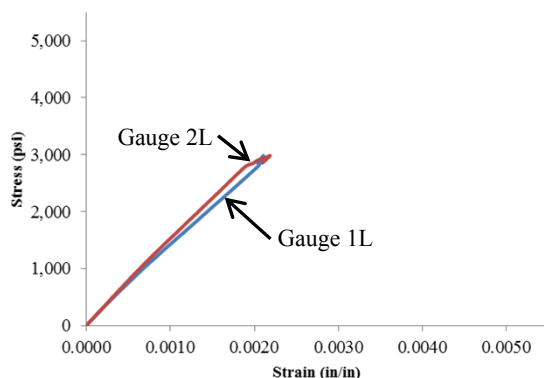
PICTURE OF SPECIMEN POST-TEST



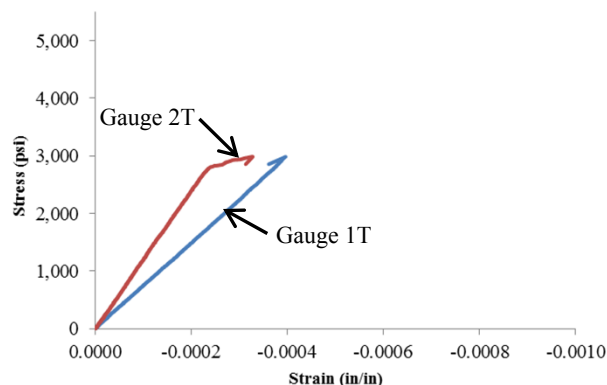
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001621 | 0.000602 | 1T | -0.000301 | -0.000120 | 0.1778 |
| 2L | 0.001500 | 0.000564 | 2T | -0.000188 | -0.000076 | 0.1198 |
| Average | | | | | | 0.1488 |

Stress-Strain Curve_-40°F_3_(09-05)_Long



Stress-Strain Curve_-40°F_3_(09-05)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-4-N40-FY09**
 Test Date: 3/30/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,472 lbs
 Poisson's Ratio, v_{xz} : 0.1252

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 0.999 in

Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 2,236 lbs

20% Max Load: 894 lbs

PICTURE OF SPECIMEN PRE-TEST



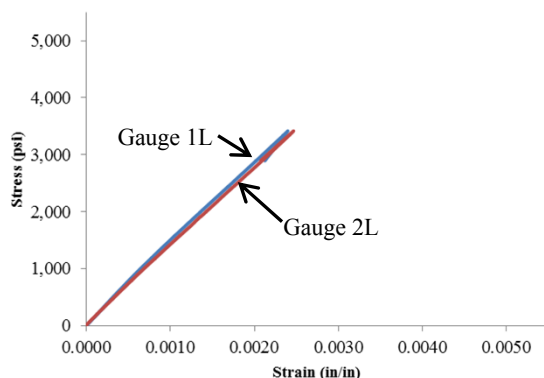
PICTURE OF SPECIMEN POST-TEST



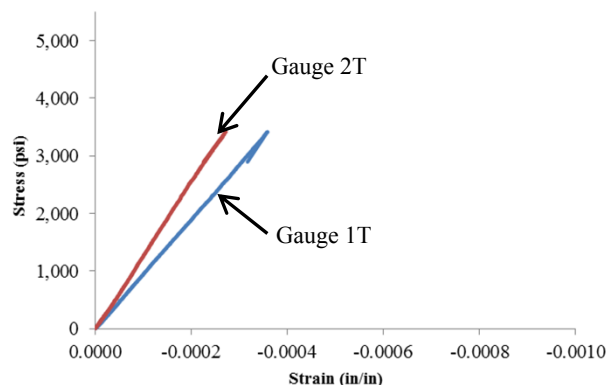
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001538 | 0.000573 | 1T | -0.000238 | -0.000096 | 0.1471 |
| 2L | 0.001600 | 0.000610 | 2T | -0.000176 | -0.000074 | 0.1034 |
| Average | | | | | | 0.1252 |

Stress-Strain Curve_-40°F_4_(09-05)_Long



Stress-Strain Curve_-40°F_4_(09-05)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-140-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-5-N40-FY09**
 Test Date: 4/2/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 4,480 lbs
 Poisson's Ratio, v_{xz} : 0.1180

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 2,240 lbs
 20% Max Load: 896 lbs

PICTURE OF SPECIMEN PRE-TEST



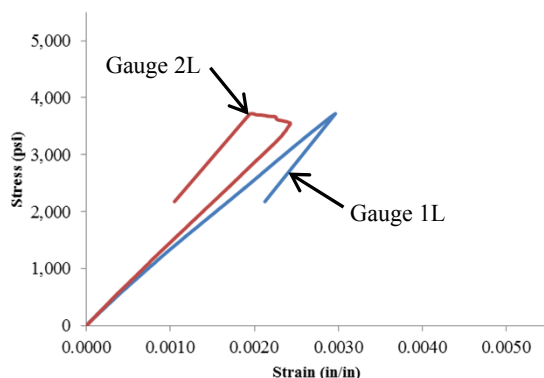
PICTURE OF SPECIMEN POST-TEST



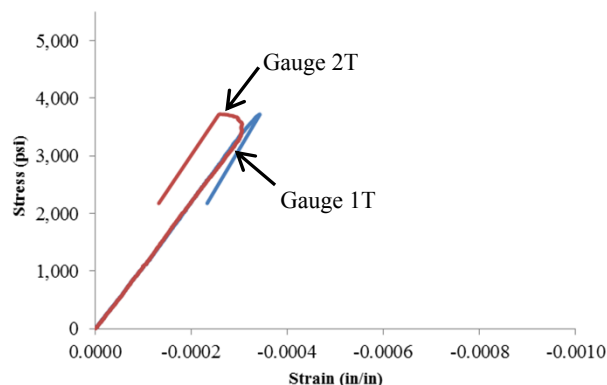
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001737 | 0.000653 | 1T | -0.000203 | -0.000083 | 0.1107 |
| 2L | 0.001556 | 0.000604 | 2T | -0.000203 | -0.000084 | 0.1253 |
| Average | | | | | | 0.1180 |

Stress-Strain Curve_-40°F_5_(09-05)_Long



Stress-Strain Curve_-40°F_5_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-140-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

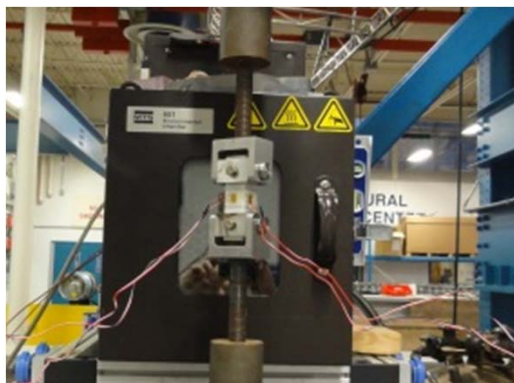
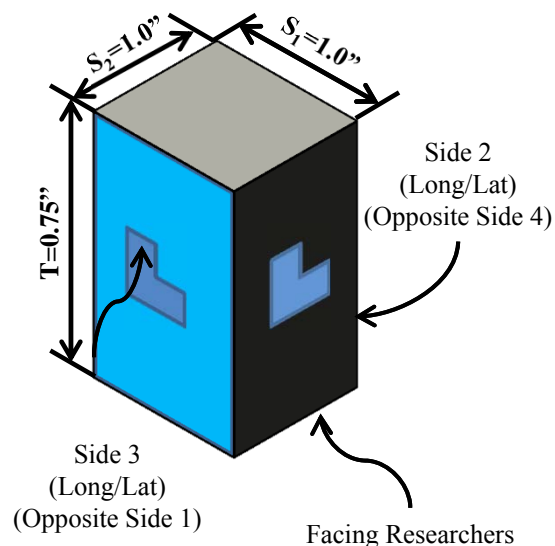
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT5-OP-70-FY09**
 Material: **Applied Poleramics SC-15, S2 Glass**
 Nominal Temperature: **70°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.1707**
 Maximum Load, P_z : **3,946 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|-------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT5-OP-1-70-FY09 | 3,951 | 0.1725 | Bondline |
| 2 | MAT5-OP-2-70-FY09 | 3,939 | 0.1597 | Bondline |
| 3 | MAT5-OP-3-70-FY09 | 3,944 | 0.2051 | Bondline |
| 4 | MAT5-OP-4-70-FY09 | 3,944 | 0.1839 | Bondline |
| 5 | MAT5-OP-5-70-FY09 | 3,951 | 0.1324 | Bondline |
| Average | | 3,946 | 0.1707 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-116 thru H-120 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Max Load is based on MAT5-TZ-70-FY09 strength data.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-1-70-FY09**
 Test Date: 11/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,951 lbs
 Poisson's Ratio, v_{xz} : 0.1725

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 1.001 in

Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,975 lbs

20% Max Load: 790 lbs

PICTURE OF SPECIMEN PRE-TEST



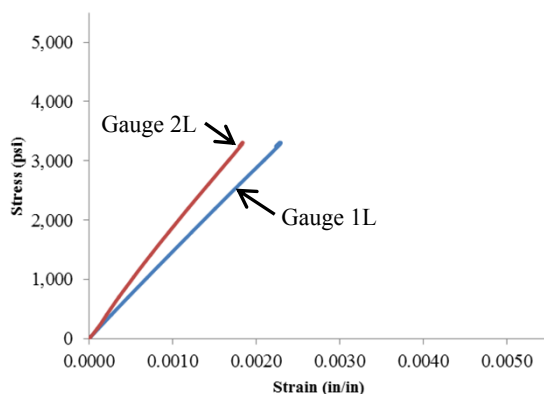
PICTURE OF SPECIMEN POST-TEST



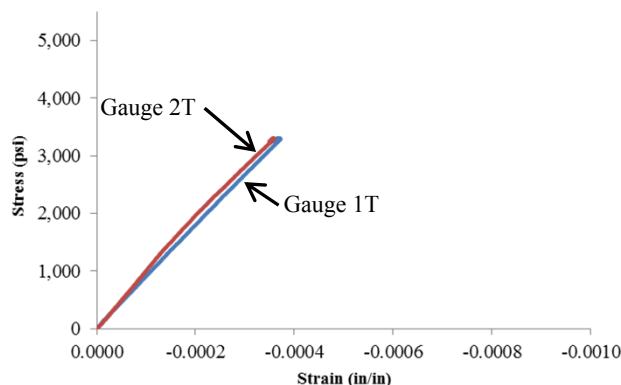
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001352 | 0.000528 | 1T | -0.000219 | -0.000087 | 0.1602 |
| 2L | 0.001055 | 0.000401 | 2T | -0.000200 | -0.000080 | 0.1848 |
| Average | | | | | | 0.1725 |

Stress-Strain Curve_70_1_(09-05)_Long



Stress-Strain Curve_70_1_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-2-70-FY09**
 Test Date: 11/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,939 lbs
 Poisson's Ratio, v_{xz} : 0.1597

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 0.998 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,970 lbs
 20% Max Load: 788 lbs

PICTURE OF SPECIMEN PRE-TEST



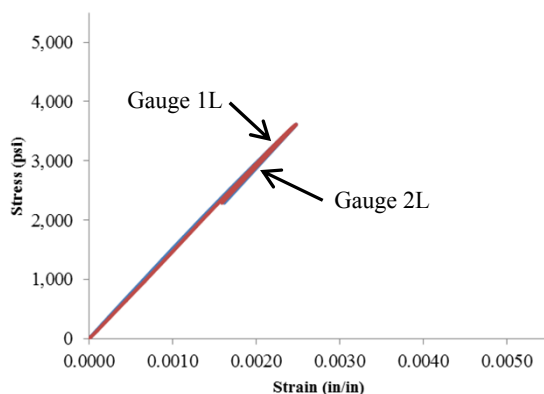
PICTURE OF SPECIMEN POST-TEST



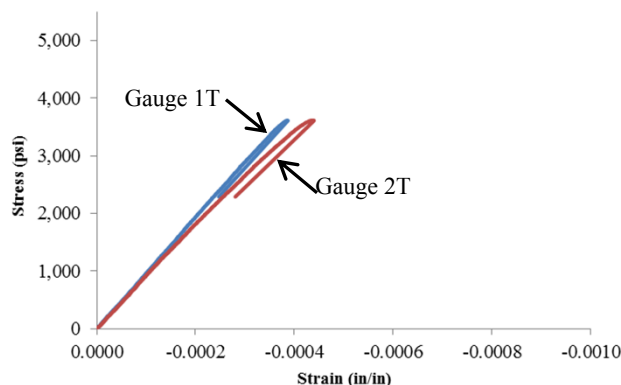
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001305 | 0.000515 | 1T | -0.000203 | -0.000083 | 0.1527 |
| 2L | 0.001334 | 0.000542 | 2T | -0.000218 | -0.000086 | 0.1667 |
| Average | | | | | | 0.1597 |

Stress-Strain Curve_70_2_(09-05)_Long



Stress-Strain Curve_70_2_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-3-70-FY09**
 Test Date: 11/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,944 lbs
 Poisson's Ratio, v_{xz} : 0.2051

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 0.999 in
 Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,972 lbs
 20% Max Load: 789 lbs

PICTURE OF SPECIMEN PRE-TEST



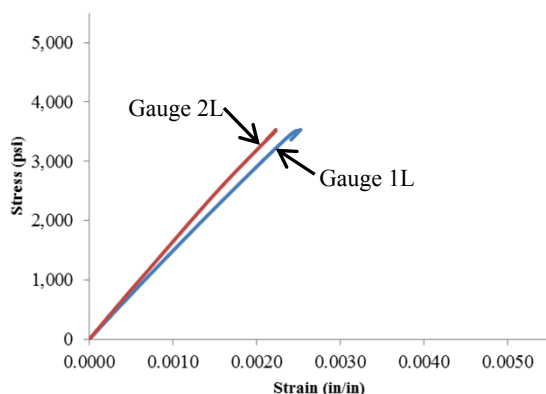
PICTURE OF SPECIMEN POST-TEST



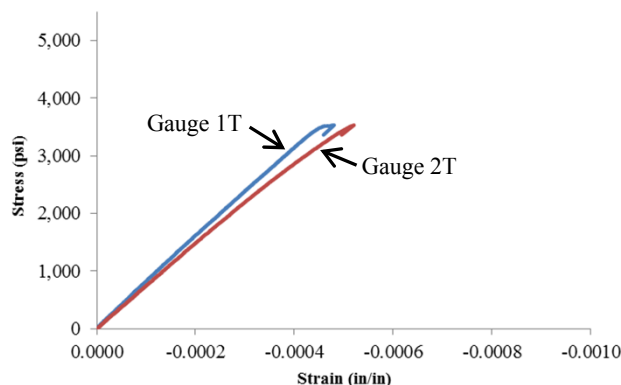
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001333 | 0.000522 | 1T | -0.000247 | -0.000095 | 0.1865 |
| 2L | 0.001200 | 0.000472 | 2T | -0.000269 | -0.000106 | 0.2237 |
| Average | | | | | | 0.2051 |

Stress-Strain Curve_70_3_(09-05)_Long



Stress-Strain Curve_70_3_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-4-70-FY09**
 Test Date: 11/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,944 lbs
 Poisson's Ratio, v_{xz} : 0.1839

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 0.999 in

Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,972 lbs

20% Max Load: 789 lbs

PICTURE OF SPECIMEN PRE-TEST



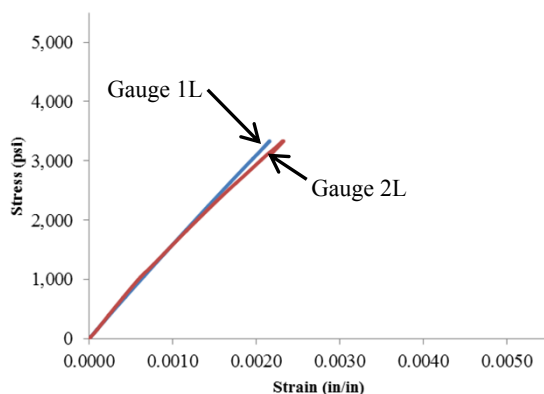
PICTURE OF SPECIMEN POST-TEST



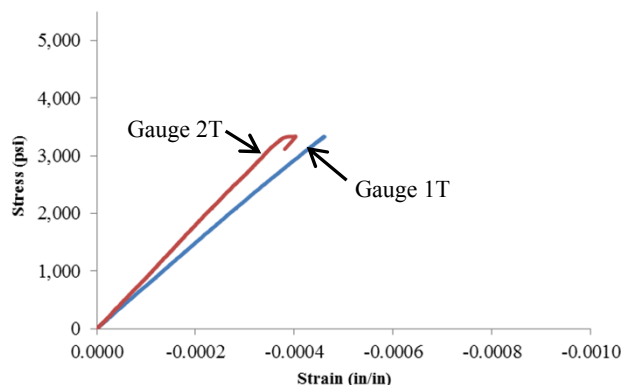
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001251 | 0.000489 | 1T | -0.000265 | -0.000106 | 0.2083 |
| 2L | 0.001273 | 0.000462 | 2T | -0.000219 | -0.000089 | 0.1594 |
| Average | | | | | | 0.1839 |

Stress-Strain Curve_70_4_(09-05)_Long



Stress-Strain Curve_70_4_(09-05)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-5-70-FY09**
 Test Date: 11/29/2011
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,951 lbs
 Poisson's Ratio, v_{xz} : 0.1324

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 1.000 in

Laboratory Temperature: 68°F

Failure Mode: Bondline

50% Max Load: 1,975 lbs

20% Max Load: 790 lbs

PICTURE OF SPECIMEN PRE-TEST



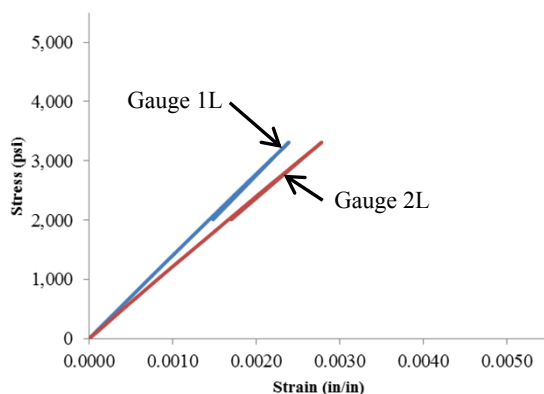
PICTURE OF SPECIMEN POST-TEST



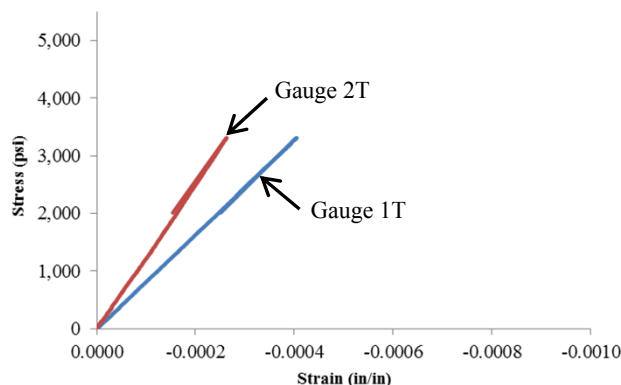
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001411 | 0.000559 | 1T | -0.000242 | -0.000098 | 0.1694 |
| 2L | 0.001638 | 0.000644 | 2T | -0.000160 | -0.000065 | 0.0954 |
| Average | | | | | | 0.1324 |

Stress-Strain Curve_70_5_(09-05)_Long



Stress-Strain Curve_70_5_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

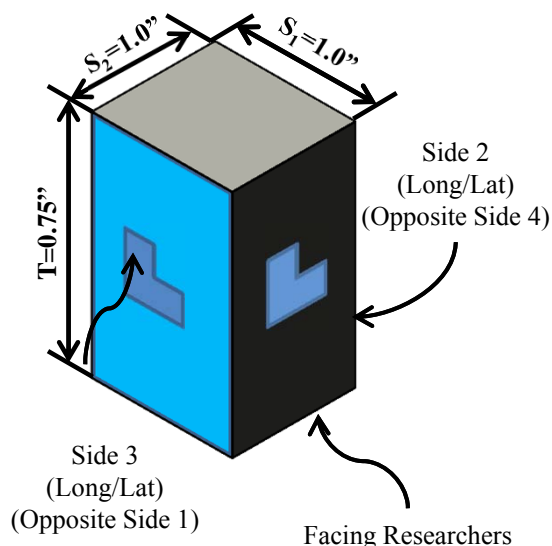
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT5-OP-140-FY09**
 Material: **Applied Poleramics SC-15, S2 Glass**
 Nominal Temperature: **140°F**
 Properties Measured:
 Average Material Properties (5 Specimens):
 Poisson’s Ratio, ν_{xz} : **0.0987**
 Maximum Load, P_z : **3,381 lbs**

| Sample | Specimen | Max Load, P_z (lb) | Poisson’s Ratio, ν_{xz} | Failure Mode |
|----------------|--------------------|-------------------------|--------------------------------|--------------|
| 1 | MAT5-OP-1-140-FY09 | 3,295 | 0.0758 | Rupture |
| 2 | MAT5-OP-2-140-FY09 | 3,414 | 0.1679 | Rupture |
| 3 | MAT5-OP-3-140-FY09 | 3,393 | 0.0865 | Bondline |
| 4 | MAT5-OP-4-140-FY09 | 3,403 | 0.0681 | Rupture |
| 5 | MAT5-OP-5-140-FY09 | 3,400 | 0.0951 | Rupture |
| Average | | 3,381 | 0.0987 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Two longitudinal strain gauges (1L and 2L) are placed on adjacent sides of the specimen and two lateral strain gauges (1T and 2T) are placed on adjacent sides as shown below. This gauge configuration will determine the value of Poisson’s Ratio on adjacent sides of the specimen.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference H-122 thru H-126 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Max Load is based on MAT5-TZ-70-FY09 strength data.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 5) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-1-140-FY09**
 Test Date: 02/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

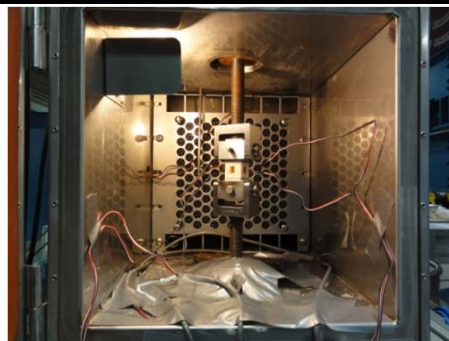
Maximum Load, P_z : 3,295 lbs
 Poisson's Ratio, v_{xz} : 0.0758

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.983 in
 Side 2: 0.981 in

Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,648 lbs
 20% Max Load: 659 lbs

PICTURE OF SPECIMEN PRE-TEST



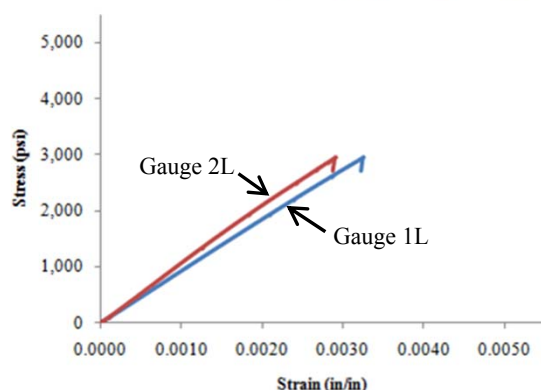
PICTURE OF SPECIMEN POST-TEST



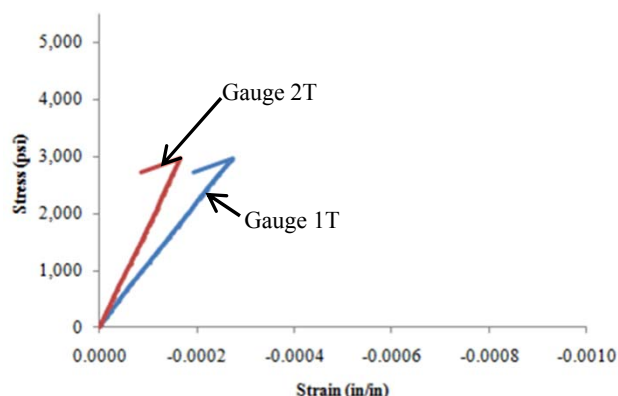
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001848 | 0.000749 | 1T | -0.000156 | -0.000059 | 0.0886 |
| 2L | 0.001612 | 0.000652 | 2T | -0.000099 | -0.000038 | 0.0631 |
| Average | | | | | | 0.0758 |

Stress-Strain Curve_140_1_(09-05)_Long



Stress-Strain Curve_140_1_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-2-140-FY09**
 Test Date: 02/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

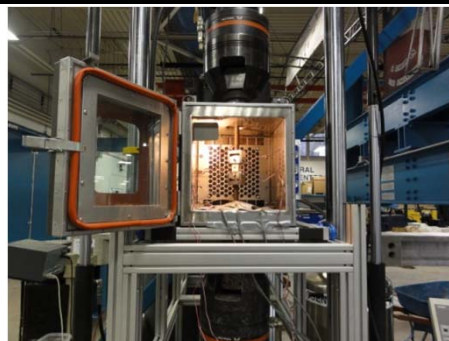
Average Material Properties:

Maximum Load, P_z : 3,414 lbs
 Poisson's Ratio, v_{xz} : 0.1679

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 0.997 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,707 lbs
 20% Max Load: 683 lbs

PICTURE OF SPECIMEN PRE-TEST



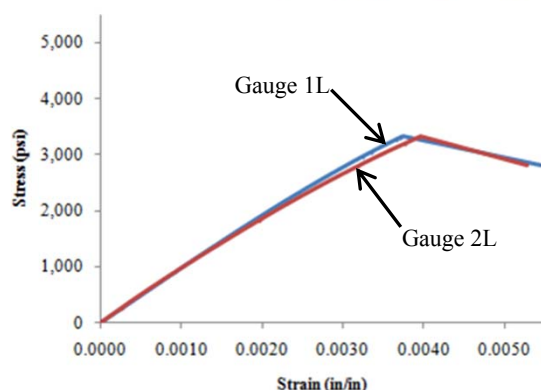
PICTURE OF SPECIMEN POST-TEST



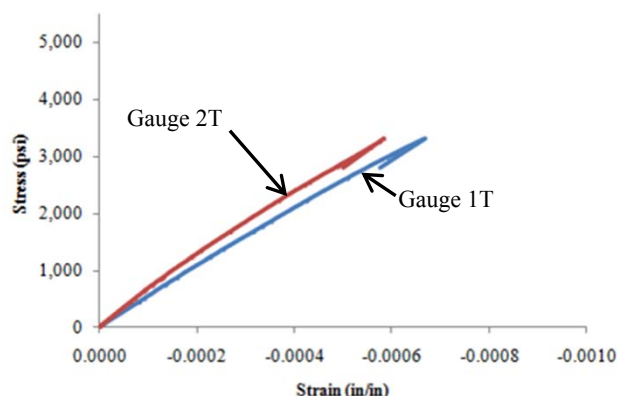
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001773 | 0.000703 | 1T | -0.000321 | -0.000125 | 0.1837 |
| 2L | 0.001824 | 0.000688 | 2T | -0.000272 | -0.000099 | 0.1521 |
| Average | | | | | | 0.1679 |

Stress-Strain Curve_140_2_(09-05)_Long



Stress-Strain Curve_140_2_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-3-140-FY09**
 Test Date: 02/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

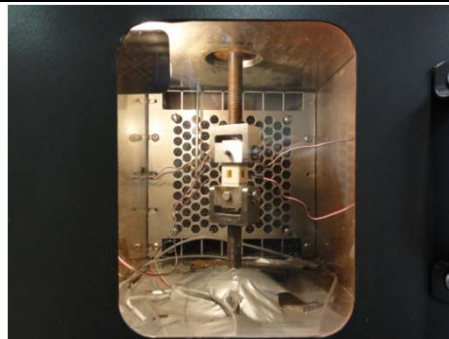
Maximum Load, P_z : 3,393 lbs
 Poisson's Ratio, v_{xz} : 0.0865

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.997 in
 Side 2: 0.996 in

Laboratory Temperature: 68°F
 Failure Mode: Bondline
 50% Max Load: 1,697 lbs
 20% Max Load: 679 lbs

PICTURE OF SPECIMEN PRE-TEST



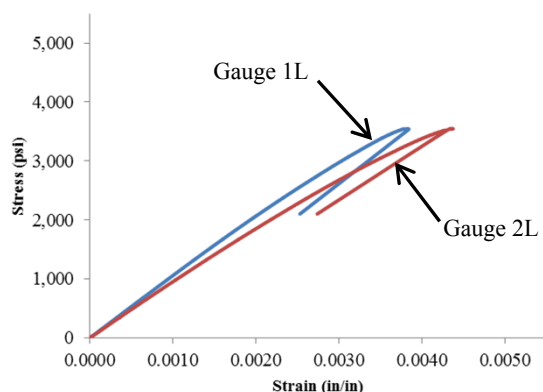
PICTURE OF SPECIMEN POST-TEST



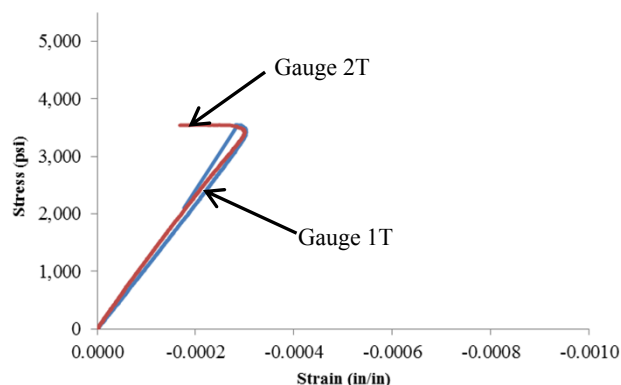
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001638 | 0.000647 | 1T | -0.000158 | -0.000064 | 0.0943 |
| 2L | 0.001838 | 0.000715 | 2T | -0.000144 | -0.000056 | 0.0786 |
| Average | | | | | | 0.0865 |

Stress-Strain Curve_140_3_(09-05)_Long



Stress-Strain Curve_140_3_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-4-140-FY09**
 Test Date: 02/17/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,403 lbs
 Poisson's Ratio, v_{xz} : 0.0681

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.997 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Load: 1,702 lbs
 20% Max Load: 681 lbs

PICTURE OF SPECIMEN PRE-TEST



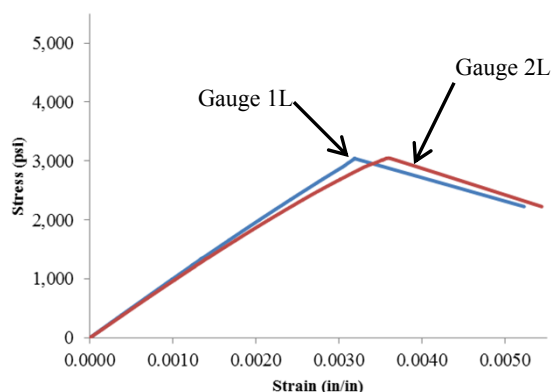
PICTURE OF SPECIMEN POST-TEST



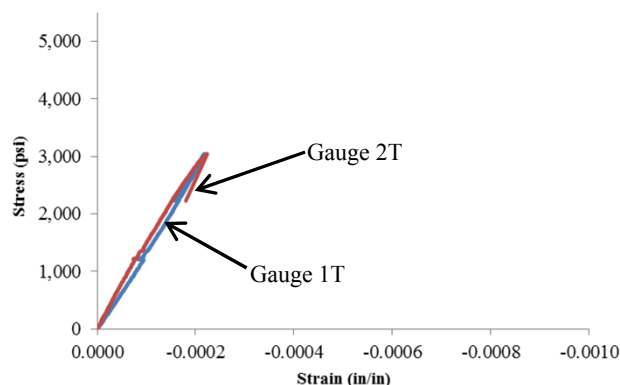
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001733 | 0.000680 | 1T | -0.000129 | -0.000055 | 0.0706 |
| 2L | 0.001818 | 0.000706 | 2T | -0.000115 | -0.000043 | 0.0655 |
| Average | | | | | | 0.0681 |

Stress-Strain Curve_140_4_(09-05)_Long



Stress-Strain Curve_140_4_(09-05)_Lat



Engineering Test notes:

- *Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides
- *Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT5-OP-5-140-FY09**
 Test Date: 02/20/2012
 Specimen Received: 7/07/2011
 Properties Measured: v_{xz}

Average Material Properties:

Maximum Load, P_z : 3,400 lbs
 Poisson's Ratio, v_{xz} : 0.0951

Measured Specimen Dimensions:

Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.997 in

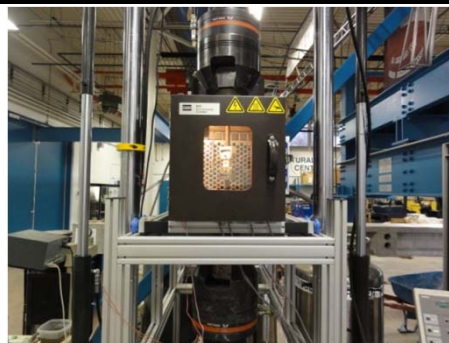
Laboratory Temperature: 68°F

Failure Mode: Rupture

50% Max Load: 1,700 lbs

20% Max Load: 680 lbs

PICTURE OF SPECIMEN PRE-TEST



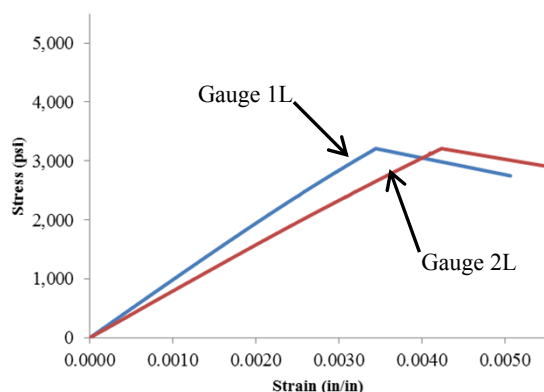
PICTURE OF SPECIMEN POST-TEST



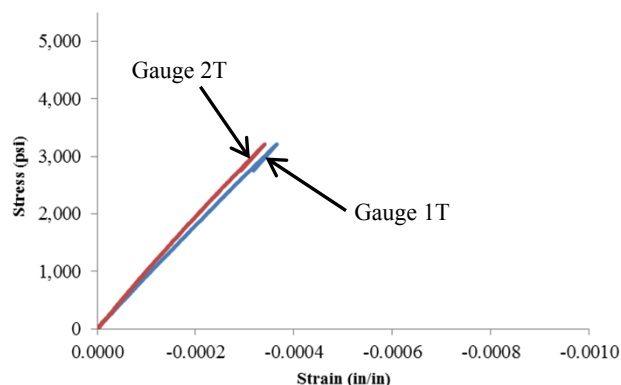
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | Lateral Gauges | | | Poisson's Ratio, v_{xz} |
|---------------------|--------------------------------|--------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|
| Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | Gauge | Strain @ 50% Max Load, (in/in) | Strain @ 20% Max Load, (in/in) | |
| 1L | 0.001750 | 0.000692 | 1T | -0.000189 | -0.000074 | 0.1092 |
| 2L | 0.002169 | 0.000861 | 2T | -0.000173 | -0.000067 | 0.0810 |
| Average | | | | | | 0.0951 |

Stress-Strain Curve_140_5_(09-05)_Long



Stress-Strain Curve_140_5_(09-05)_Lat



Engineering Test notes:

*Specimen was fitted with two Vishay C2A-06-125LT-350 strain gauges on adjacent sides

*Poisson's Ratio was calculated using strain at 20% and 50% of max load (based on MAT5-TZ-70-FY09 data)

*Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX I

MATERIAL 6-FY09 TESTING RESULTS

UNCLASSIFIED

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-TX-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: -40°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 15,918 | lbs |
| Tensile Strength, ST_x : | 59,658 | psi |
| Tensile Modulus, E_x : | 6,630,993 | psi |
| Ultimate Strain, ϵ_x : | 0.0091 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.5618 | |

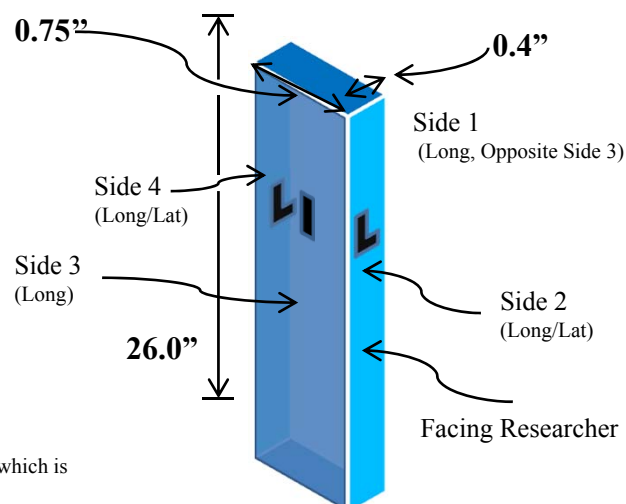
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT6-TX-1-N40-FY09 | 16,288 | 61,784 | 5,485,924 | 0.0113 | 0.6534 | AGM |
| 2 | MAT6-TX-2-N40-FY09 | 16,540 | 63,161 | 7,270,666 | 0.0087 | 0.5721 | AGM |
| 3 | MAT6-TX-3-N40-FY09 | 15,828 | 58,211 | 7,286,002 | 0.0080 | 0.5649 | AGM |
| 4 | MAT6-TX-4-N40-FY09 | 16,147 | 60,158 | 6,094,011 | 0.0099 | 0.4691 | AGM |
| 5 | MAT6-TX-5-N40-FY09 | 14,788 | 54,977 | 7,018,362 | 0.0078 | 0.5496 | AGM |
| Average | | 15,918 | 59,658 | 6,630,993 | 0.0091 | 0.5618 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen. For this material, the nominal thickness is reduced for a length of 4" to a value of 0.4" in the test region where strain gauges are located.

-40°F Temperature Test Condition**Notes:**

- 1) 7 specimens tested, group of 5 displayed with relevant data shown
- 2) AGM corresponds with A=angled, G=gauge area, M=middle of specimen
- 3) See I-2 to I-6 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-30% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-1-N40-FY09**
 Test Date: 10/26/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

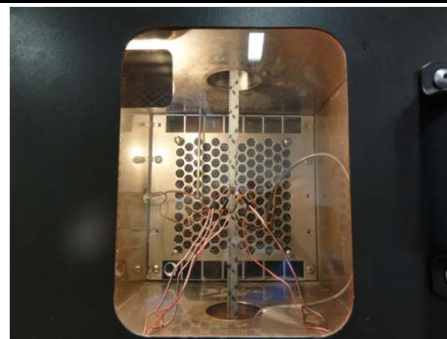
Ultimate Load, P_x : 16,288 lbs
 Tensile Strength, ST_x : 61,784 psi
 Tensile Modulus, E_x : 5,485,924 psi
 Ultimate Strain, ϵ_x : 0.0113 in/in
 Poisson's Ratio, v_{xy} : 0.6534

Measured Specimen Dimensions:

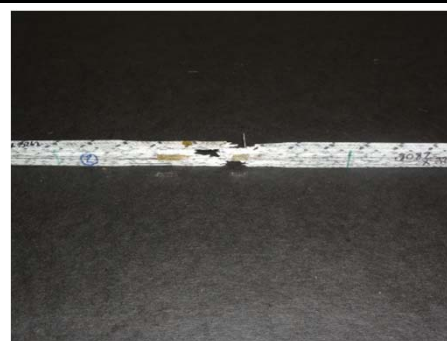
Width, W: 0.3262 in
 Thickness, H: 0.8082 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,629 lbs
 30% Max Load: 4,887 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

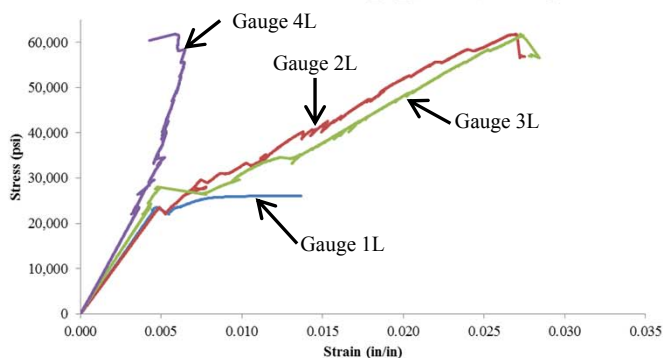


PICTURE OF SPECIMEN POST-TEST

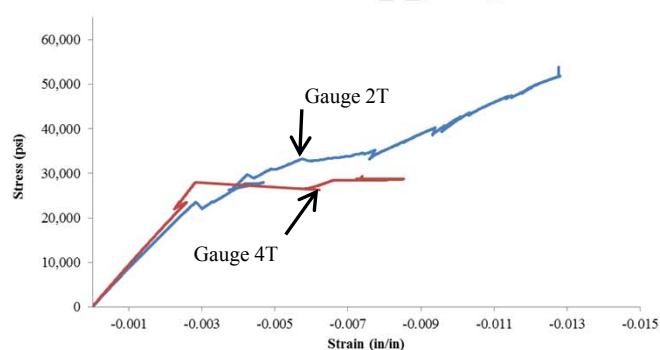


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0037 | 0.0013 | 5,095,458 | | | | |
| 2L | 0.0038 | 0.0013 | 4,869,317 | 2T | -0.0022 | -0.0007 | 0.5890 |
| 3L | 0.0034 | 0.0011 | 5,450,670 | | | | |
| 4L | 0.0029 | 0.0010 | 6,528,250 | 4T | -0.0020 | -0.0006 | 0.7178 |
| Average | | | 5,485,924 | | | | 0.6534 |

Stress-Strain Curve N40_1_(09-06), Long.



Stress-Strain Curve N40_1_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-2-N40-FY09**
 Test Date: 11/04/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 16,540 lbs
 Tensile Strength, ST_x : 63,161 psi
 Tensile Modulus, E_x : 7,270,666 psi
 Ultimate Strain, ϵ_x : 0.0087 in/in
 Poisson's Ratio, v_{xy} : 0.5721

Measured Specimen Dimensions:

Width, W: 0.3284 in
 Thickness, H: 0.7974 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,654 lbs
 30% Max Load: 4,962 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

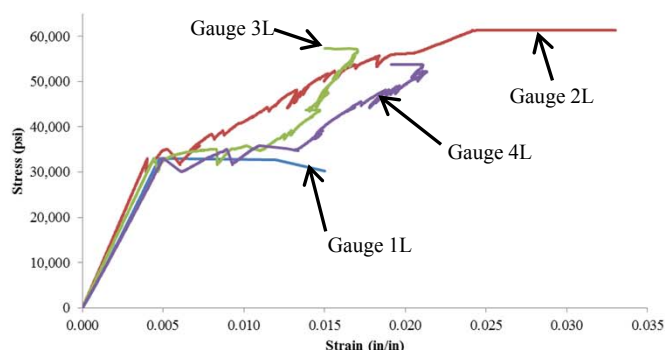


PICTURE OF SPECIMEN POST-TEST

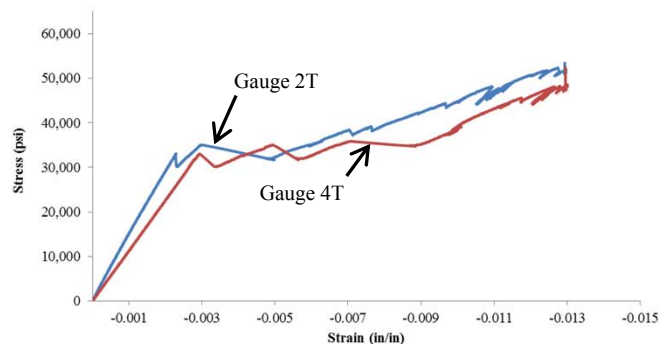


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0028 | 0.0010 | 6,912,545 | | | | |
| 2L | 0.0023 | 0.0008 | 8,200,496 | 2T | -0.0013 | -0.0004 | 0.5632 |
| 3L | 0.0025 | 0.0008 | 7,421,580 | | | | |
| 4L | 0.0029 | 0.0010 | 6,548,042 | 4T | -0.0017 | -0.0006 | 0.5811 |
| Average | | | 7,270,666 | | | | 0.5721 |

Stress-Strain Curve N40_2_(09-06), Long.



Stress-Strain Curve N40_2_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-3-N40-FY09**
 Test Date: 11/04/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

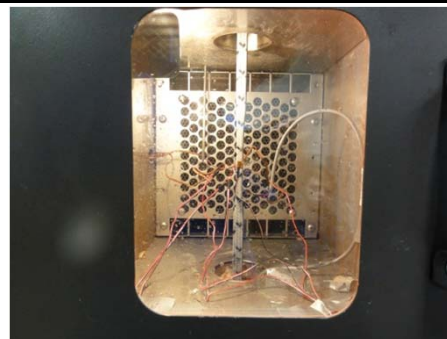
Ultimate Load, P_x : 15,828 lbs
 Tensile Strength, ST_x : 58,211 psi
 Tensile Modulus, E_x : 7,286,002 psi
 Ultimate Strain, ϵ_x : 0.0080 in/in
 Poisson's Ratio, v_{xy} : 0.5649

Measured Specimen Dimensions:

Width, W: 0.3305 in
 Thickness, H: 0.8227 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,583 lbs
 30% Max Load: 4,748 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

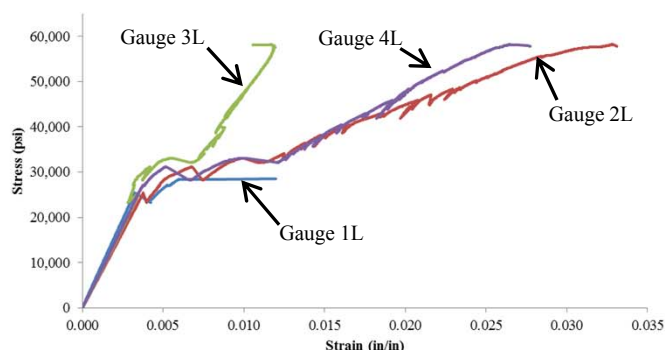


PICTURE OF SPECIMEN POST-TEST

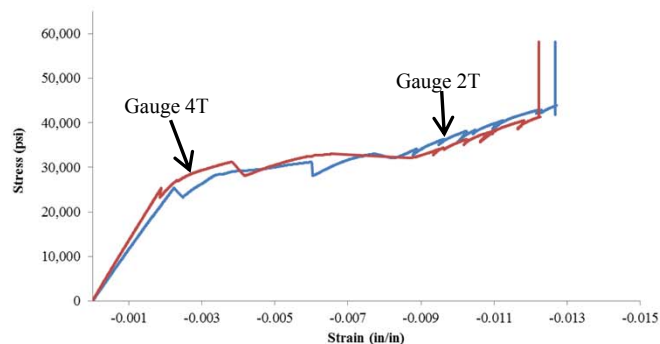


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0022 | 0.0007 | 7,806,426 | | | | |
| 2L | 0.0026 | 0.0009 | 6,746,396 | 2T | -0.0015 | -0.0005 | 0.5850 |
| 3L | 0.0025 | 0.0009 | 7,266,526 | | | | |
| 4L | 0.0024 | 0.0008 | 7,324,658 | 4T | -0.0013 | -0.0004 | 0.5447 |
| Average | | | 7,286,002 | | | | 0.5649 |

Stress-Strain Curve N40_3_(09-06), Long.



Stress-Strain Curve N40_3_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-4-N40-FY09**
 Test Date: 11/23/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

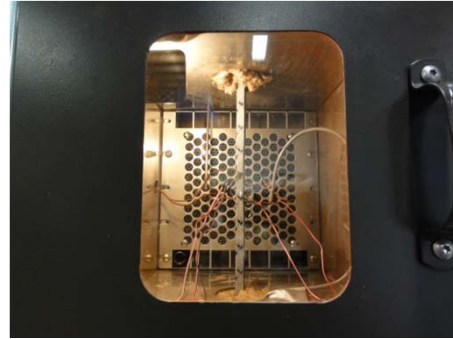
Ultimate Load, P_x : 16,147 lbs
 Tensile Strength, ST_x : 60,158 psi
 Tensile Modulus, E_x : 6,094,011 psi
 Ultimate Strain, ϵ_x : 0.0099 in/in
 Poisson's Ratio, v_{xy} : 0.4691

Measured Specimen Dimensions:

Width, W: 0.3359 in
 Thickness, H: 0.7991 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,615 lbs
 30% Max Load: 4,844 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

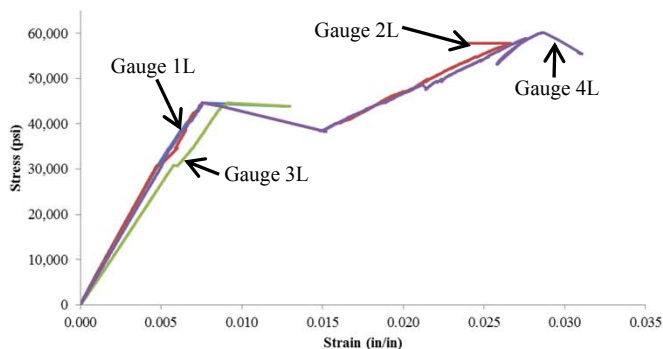


PICTURE OF SPECIMEN POST-TEST

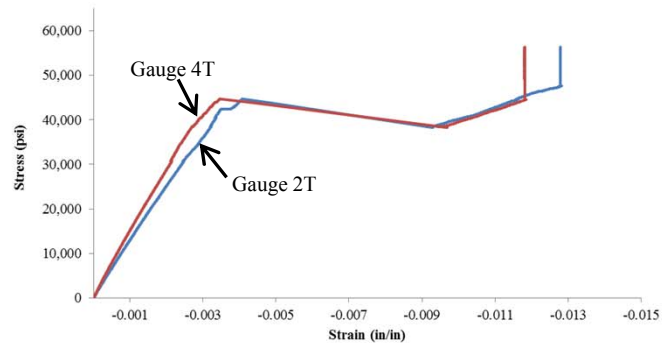


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0028 | 0.0009 | 6,387,075 | | | | |
| 2L | 0.0028 | 0.0009 | 6,512,681 | 2T | -0.0014 | -0.0004 | 0.5170 |
| 3L | 0.0034 | 0.0012 | 5,371,774 | | | | |
| 4L | 0.0030 | 0.0010 | 6,104,513 | 4T | -0.0012 | -0.0004 | 0.4212 |
| Average | | | 6,094,011 | | | | 0.4691 |

Stress-Strain Curve N40_4_(09-06), Long.



Stress-Strain Curve N40_4_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-5-N40-FY09**
 Test Date: 1/24/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 14,788 lbs
 Tensile Strength, ST_x : 54,977 psi
 Tensile Modulus, E_x : 7,018,362 psi
 Ultimate Strain, ϵ_x : 0.0078 in/in
 Poisson's Ratio, v_{xy} : 0.5496

Measured Specimen Dimensions:

Width, W: 0.3300 in
 Thickness, H: 0.8151 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,479 lbs
 30% Max Load: 4,436 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

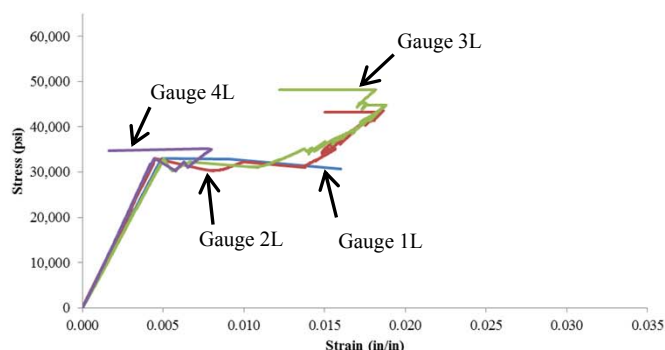


PICTURE OF SPECIMEN POST-TEST

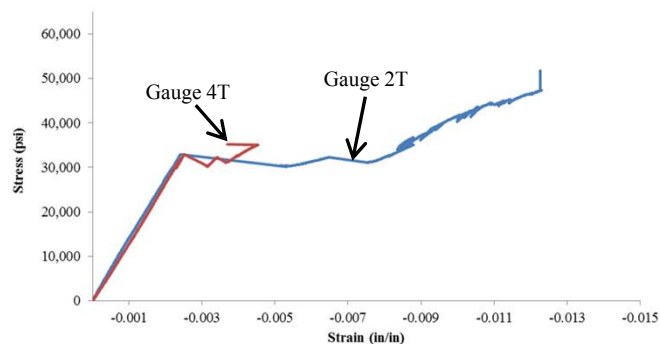


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0025 | 0.0008 | 6,755,551 | | | | |
| 2L | 0.0023 | 0.0008 | 7,180,277 | 2T | -0.0012 | -0.0004 | 0.5265 |
| 3L | 0.0025 | 0.0009 | 6,637,032 | | | | |
| 4L | 0.0022 | 0.0008 | 7,500,587 | 4T | -0.0013 | -0.0004 | 0.5727 |
| Average | | | 7,018,362 | | | | 0.5496 |

Stress-Strain Curve N40_5_(09-06), Long.



Stress-Strain Curve N40_5_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-TX-70-FY09
Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric
Nominal Temperature: 70°F
Properties Measured: ST_x , E_x , ν_{xy}
Average Material Properties (5 Specimens):
Ultimate Load, P_x : 14,228 lbs
Tensile Strength, ST_x : 44,896 psi
Tensile Modulus, E_x : 6,812,287 psi
Ultimate Strain, ϵ_x : 0.0067 in/in
Poisson's Ratio, ν_{xy} : 0.6234

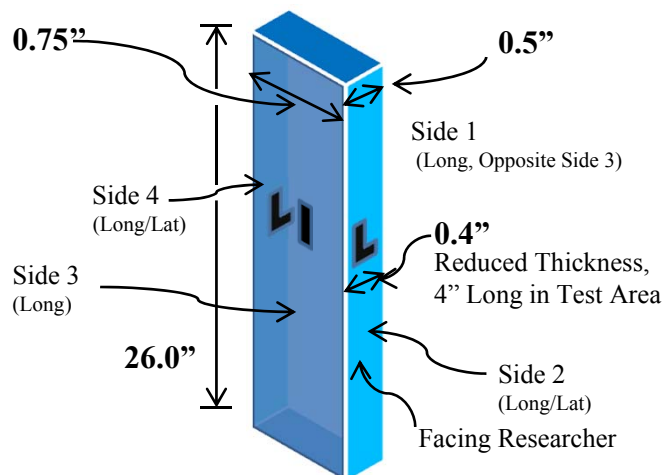
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|-------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT6-TX-70-FY09-1 | 14,893 | 44,568 | 6,749,003 | 0.0066 | 0.5868 | AGM |
| 2 | MAT6-TX-70-FY09-2 | 14,093 | 45,568 | 7,339,908 | 0.0062 | 0.5530 | AGM |
| 3 | MAT6-TX-70-FY09-3 | 14,581 | 44,015 | 6,534,413 | 0.0067 | 0.4576 | AGM |
| 4 | MAT6-TX-70-FY09-4 | 15,124 | 47,865 | 5,883,871 | 0.0081 | 0.7238 | AGM |
| 5 | MAT6-TX-70-FY09-5 | 13,116 | 42,134 | 7,490,957 | 0.0056 | 0.7592 | AGM |
| Average | | 14,228 | 44,896 | 6,812,287 | 0.0067 | 0.6234 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen. For this material, the nominal thickness is reduced for a length of 4" to a value of 0.4" in the test region where strain gauges are located.

70°F Temperature Test Condition**Notes:**

- 1) 12 specimens tested, group of 5 displayed with relevant data shown
- 2) AGM corresponds with A=angled, G=gauge area, M=middle of specimen
- 3) See I-8 to I-12 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-30% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-1-70-FY09**
 Test Date: 8/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

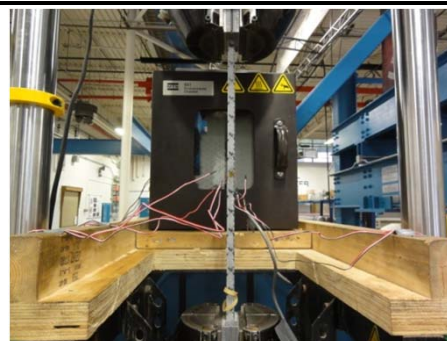
Average Material Properties:

Ultimate Load, P_x : 14,893 lbs
 Tensile Strength, ST_x : 44,568 psi
 Tensile Modulus, E_x : 6,749,003 psi
 Ultimate Strain, ϵ_x : 0.0066 in/in
 Poisson's Ratio, ν_{xy} : 0.5868

Measured Specimen Dimensions:

Width, W: 0.4100 in
 Thickness, H: 0.8150 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,489 lbs
 30% Max Load: 4,468 lbs

PICTURE OF SPECIMEN PRE-TEST



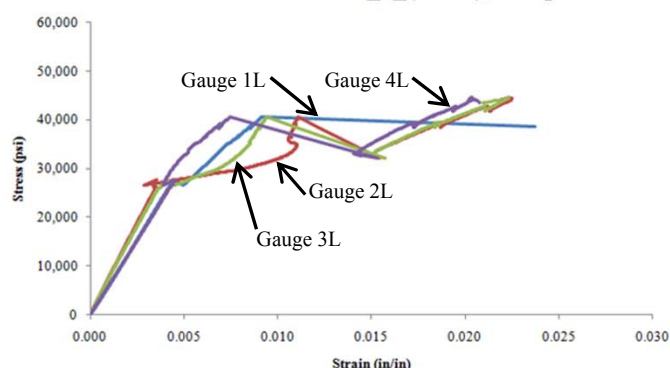
PICTURE OF SPECIMEN POST-TEST



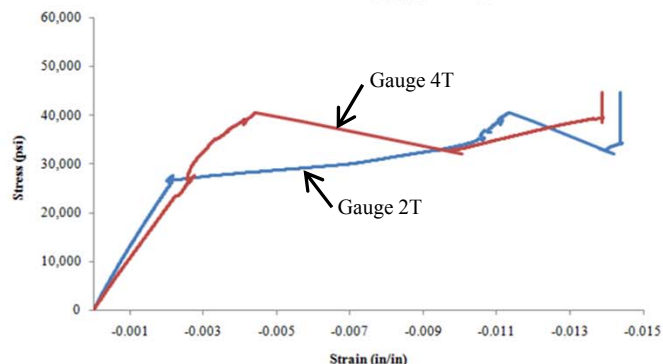
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0022 | 0.0008 | 6,211,390 | | | | |
| 2L | 0.0018 | 0.0006 | 7,537,631 | 2T | -0.0010 | -0.0003 | 0.5899 |
| 3L | 0.0018 | 0.0006 | 7,173,974 | | | | |
| 4L | 0.0022 | 0.0007 | 6,073,017 | 4T | -0.0013 | -0.0004 | 0.5837 |
| Average | | | 6,749,003 | | | | 0.5868 |

Stress-Strain Curve 70_1_(09-06), Long.



Stress-Strain Curve 70_1_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-2-70-FY09**
 Test Date: 8/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 14,093 lbs
 Tensile Strength, ST_x : 45,568 psi
 Tensile Modulus, E_x : 7,339,908 psi
 Ultimate Strain, ϵ_x : 0.0062 in/in
 Poisson's Ratio, v_{xy} : 0.5530

Measured Specimen Dimensions:

Width, W: 0.3790 in
 Thickness, H: 0.8160 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,409 lbs
 30% Max Load: 4,228 lbs

PICTURE OF SPECIMEN PRE-TEST



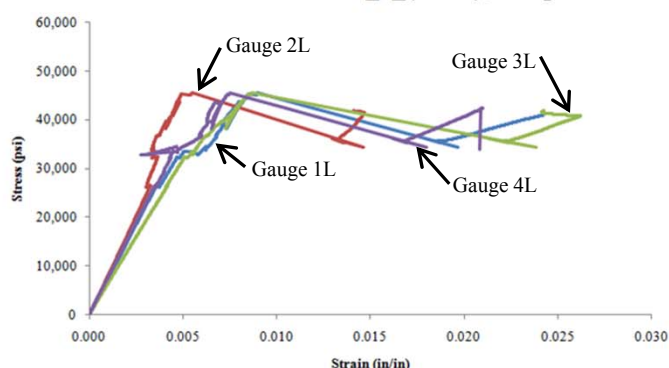
PICTURE OF SPECIMEN POST-TEST



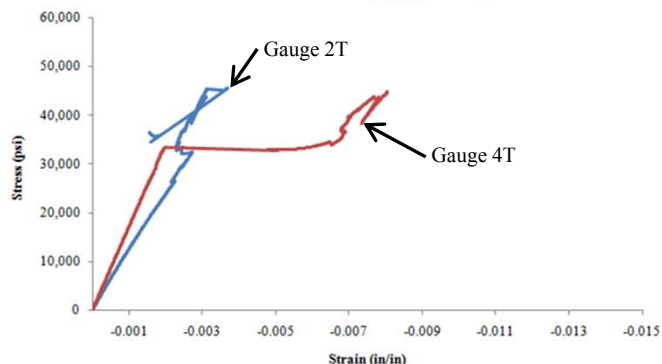
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0019 | 0.0006 | 7,410,797 | | | | |
| 2L | 0.0017 | 0.0006 | 8,027,376 | 2T | -0.0011 | -0.0003 | 0.6605 |
| 3L | 0.0021 | 0.0007 | 6,342,743 | | | | |
| 4L | 0.0018 | 0.0006 | 7,578,716 | 4T | -0.0008 | -0.0003 | 0.4455 |
| Average | | | 7,339,908 | | | | 0.5530 |

Stress-Strain Curve 70_2_(09-06), Long.



Stress-Strain Curve 70_2_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-3-70-FY09**
 Test Date: 8/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 14,581 lbs
 Tensile Strength, ST_x : 44,015 psi
 Tensile Modulus, E_x : 6,534,413 psi
 Ultimate Strain, ϵ_x : 0.0067 in/in
 Poisson's Ratio, ν_{xy} : 0.4576

Measured Specimen Dimensions:

Width, W: 0.4100 in
 Thickness, H: 0.8080 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,458 lbs
 30% Max Load: 4,374 lbs

PICTURE OF SPECIMEN PRE-TEST



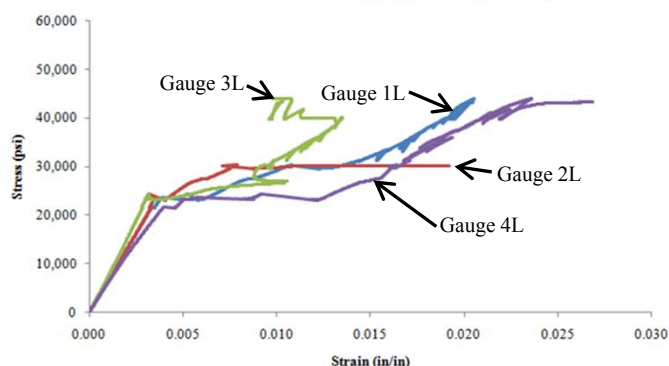
PICTURE OF SPECIMEN POST-TEST



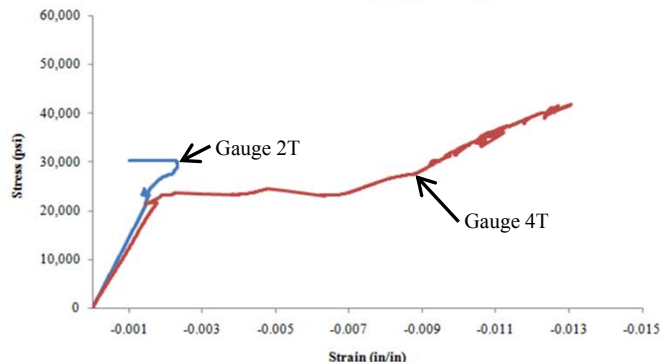
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0020 | 0.0007 | 6,496,054 | | | | |
| 2L | 0.0020 | 0.0007 | 6,478,685 | 2T | -0.0009 | -0.0003 | 0.4500 |
| 3L | 0.0018 | 0.0006 | 7,501,635 | | | | |
| 4L | 0.0023 | 0.0007 | 5,661,281 | 4T | -0.0011 | -0.0003 | 0.4651 |
| Average | | | 6,534,413 | | | | 0.4576 |

Stress-Strain Curve 70_3_(09-06), Long.



Stress-Strain Curve 70_3_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-4-70-FY09**
 Test Date: 8/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 15,124 lbs
 Tensile Strength, ST_x : 47,865 psi
 Tensile Modulus, E_x : 5,883,871 psi
 Ultimate Strain, ϵ_x : 0.0081 in/in
 Poisson's Ratio, ν_{xy} : 0.7238

Measured Specimen Dimensions:

Width, W: 0.3830 in
 Thickness, H: 0.8250 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,512 lbs
 30% Max Load: 4,537 lbs

PICTURE OF SPECIMEN PRE-TEST



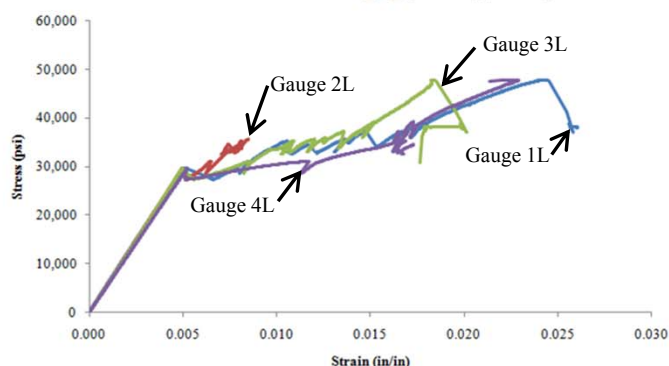
PICTURE OF SPECIMEN POST-TEST



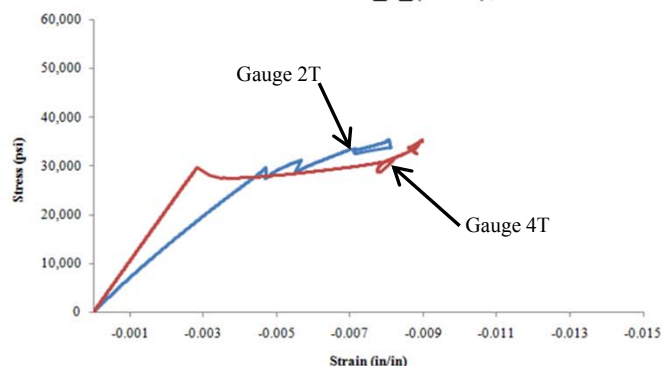
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0024 | 0.0008 | 5,927,998 | | | | |
| 2L | 0.0024 | 0.0008 | 5,968,279 | 2T | -0.0021 | -0.0007 | 0.9072 |
| 3L | 0.0024 | 0.0008 | 5,948,070 | | | | |
| 4L | 0.0025 | 0.0008 | 5,691,134 | 4T | -0.0014 | -0.0005 | 0.5404 |
| Average | | | 5,883,871 | | | | 0.7238 |

Stress-Strain Curve 70_4_(09-06), Long.



Stress-Strain Curve 70_4_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-5-70-FY09**
 Test Date: 8/04/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 13,116 lbs
 Tensile Strength, ST_x : 42,134 psi
 Tensile Modulus, E_x : 7,490,957 psi
 Ultimate Strain, ϵ_x : 0.0056 in/in
 Poisson's Ratio, v_{xy} : 0.7592

Measured Specimen Dimensions:

Width, W : 0.3764 in
 Thickness, H : 0.8270 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,312 lbs
 30% Max Load: 3,935 lbs

PICTURE OF SPECIMEN PRE-TEST



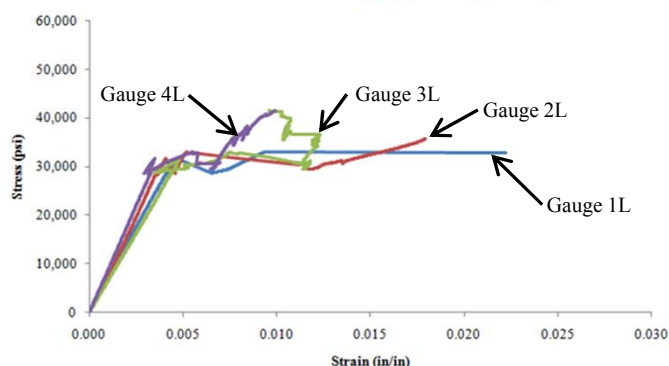
PICTURE OF SPECIMEN POST-TEST



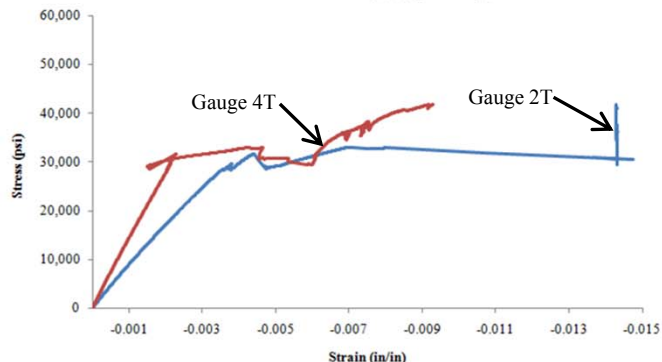
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0018 | 0.0006 | 6,996,937 | | | | |
| 2L | 0.0017 | 0.0006 | 7,731,616 | 2T | -0.0014 | -0.0005 | 0.9044 |
| 3L | 0.0019 | 0.0007 | 6,515,407 | | | | |
| 4L | 0.0015 | 0.0005 | 8,719,868 | 4T | -0.0009 | -0.0003 | 0.6140 |
| Average | | | 7,490,957 | | | | 0.7592 |

Stress-Strain Curve 70_5_(09-06), Long.



Stress-Strain Curve 70_5_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area. The specimen also exhibits a long splitting failure originating from the gauge area (SGM)
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Tensile Test

TEST: (ASTM D3039/D3039 M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-TX-140-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 140°F

Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

| | | |
|---------------------------------|-----------|-------|
| Ultimate Load, P_x : | 11,624 | lbs |
| Tensile Strength, ST_x : | 35,317 | psi |
| Tensile Modulus, E_x : | 5,666,334 | psi |
| Ultimate Strain, ϵ_x : | 0.0063 | in/in |
| Poisson's Ratio, ν_{xy} : | 0.8875 | |

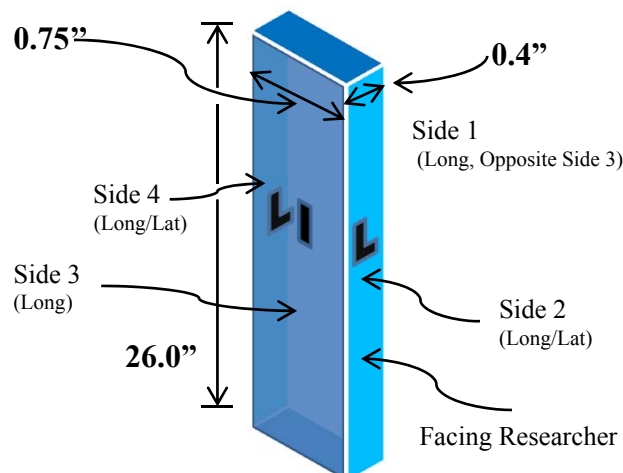
| Sample | Specimen | Ultimate Load, P_x (lbs) | Tensile Strength, ST_x (psi) | Tensile Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|----------------|--------------------|----------------------------|--------------------------------|------------------------------|---------------------------------------|-----------------------------|--------------|
| 1 | MAT6-TX-1-140-FY09 | 9,337 | 29,203 | 6,818,704 | 0.0043 | 0.8734 | AGM |
| 2 | MAT6-TX-2-140-FY09 | 12,624 | 39,900 | 5,619,970 | 0.0071 | 0.9955 | AGM |
| 3 | MAT6-TX-3-140-FY09 | 12,550 | 36,745 | 5,243,479 | 0.0070 | 0.7165 | AGM |
| 4 | MAT6-TX-4-140-FY09 | 11,907 | 37,209 | 5,113,242 | 0.0073 | 1.0903 | AGM |
| 5 | MAT6-TX-5-140-FY09 | 11,700 | 33,527 | 5,536,273 | 0.0061 | 0.7619 | AGM |
| Average | | 11,624 | 35,317 | 5,666,334 | 0.0063 | 0.8875 | - |

Test Description:

The In-Plane Tensile Test, performed within guidance of ASTM D3039, measures the In-Plane Tensile Strength, Elastic Modulus and Poisson's Ratio of fiber reinforced polymer matrix composite materials. Fibers are oriented in two dimensions, along the "x" and "y" planes. There are no fibers along the third, "z", axis. For this test, a tensile load is applied parallel to one fiber direction. The test displacement rate is 0.05 in/min. The test is performed on the Instron 8502A which has a universal joint attached to the upper head. The universal joint allows for uniaxial tension throughout the specimen. Longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral (transverse) strain gauges (2T and 4T) are placed on opposite sides of the specimen. For this material, the nominal thickness is reduced for a length of 4" to a value of 0.4" in the test region where strain gauges are located.

140°F Temperature Test Condition**Notes:**

- 1) 7 specimens tested, group of 5 displayed with relevant data shown
- 2) AGM corresponds with A=angled, G=gauge area, M=middle of specimen
- 3) See I-14 to I-18 for individual specimen results
- 4) The ultimate strain recorded above is calculated using the elastic modulus which is based on the 10-30% region of the stress-strain curve

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-1-140-FY09**
 Test Date: 10/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

Ultimate Load, P_x : 9,337 lbs
 Tensile Strength, ST_x : 29,203 psi
 Tensile Modulus, E_x : 6,818,704 psi
 Ultimate Strain, ϵ_x : 0.0043 in/in
 Poisson's Ratio, v_{xy} : 0.8734

Measured Specimen Dimensions:

Width, W: 0.4042 in
 Thickness, H: 0.7910 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 934 lbs
 30% Max Load: 2,801 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

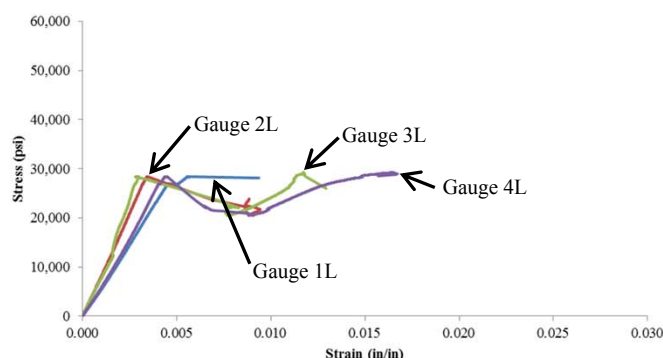


PICTURE OF SPECIMEN POST-TEST

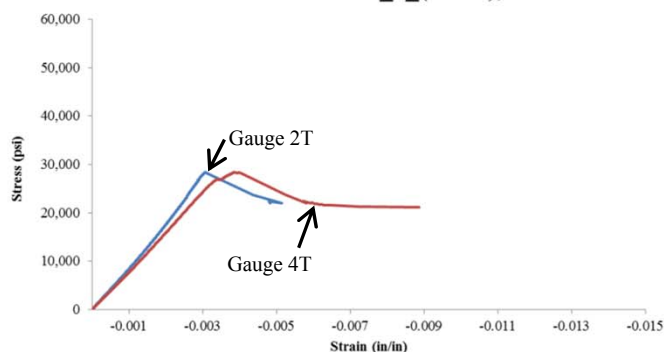


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0016 | 0.0006 | 5,741,614 | | | | |
| 2L | 0.0011 | 0.0004 | 8,119,455 | 2T | -0.0010 | -0.0003 | 0.9622 |
| 3L | 0.0012 | 0.0004 | 7,324,155 | | | | |
| 4L | 0.0015 | 0.0005 | 6,089,591 | 4T | -0.0011 | -0.0004 | 0.7846 |
| Average | | | 6,818,704 | | | | 0.8734 |

Stress-Strain Curve 140_1_(09-06), Long.



Stress-Strain Curve 140_1_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-2-140-FY09**
 Test Date: 10/03/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

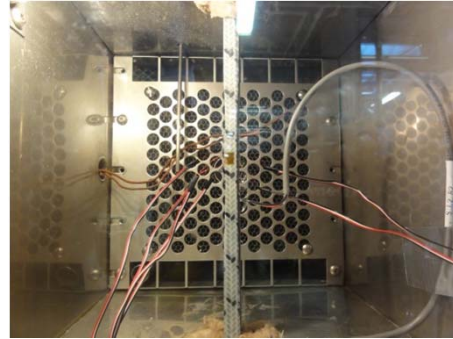
Ultimate Load, P_x : 12,624 lbs
 Tensile Strength, ST_x : 39,900 psi
 Tensile Modulus, E_x : 5,619,970 psi
 Ultimate Strain, ϵ_x : 0.0071 in/in
 Poisson's Ratio, v_{xy} : 0.9955

Measured Specimen Dimensions:

Width, W : 0.3955 in
 Thickness, H : 0.8000 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,262 lbs
 30% Max Load: 3,787 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

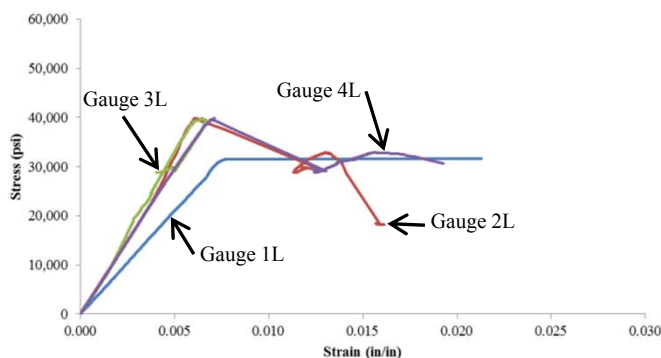


PICTURE OF SPECIMEN POST-TEST

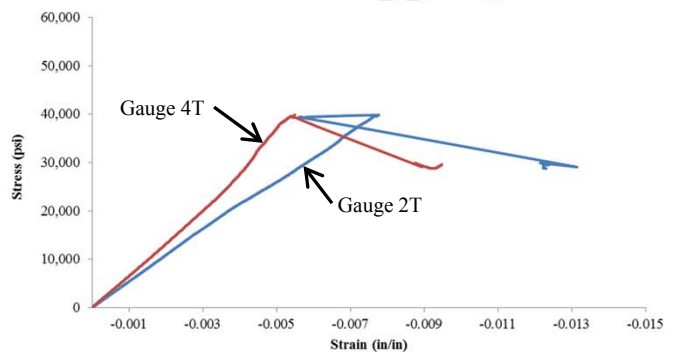


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0029 | 0.0010 | 4,228,070 | | | | |
| 2L | 0.0020 | 0.0007 | 5,888,693 | 2T | -0.0022 | -0.0007 | 1.0784 |
| 3L | 0.0019 | 0.0007 | 6,394,417 | | | | |
| 4L | 0.0020 | 0.0007 | 5,968,702 | 4T | -0.0018 | -0.0006 | 0.9126 |
| Average | | | 5,619,970 | | | | 0.9955 |

Stress-Strain Curve 140_2_(09-06), Long.



Stress-Strain Curve 140_2_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-3-140-FY09**
 Test Date: 10/17/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

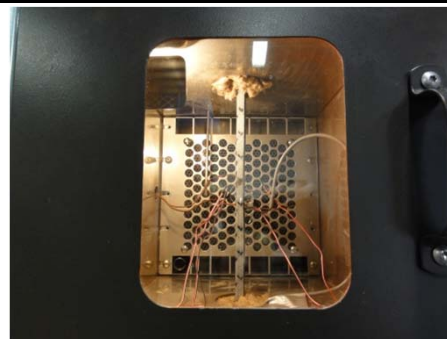
Ultimate Load, P_x : 12,550 lbs
 Tensile Strength, ST_x : 36,745 psi
 Tensile Modulus, E_x : 5,243,479 psi
 Ultimate Strain, ϵ_x : 0.0070 in/in
 Poisson's Ratio, v_{xy} : 0.7165

Measured Specimen Dimensions:

Width, W: 0.4140 in
 Thickness, H: 0.8250 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,255 lbs
 30% Max Load: 3,765 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

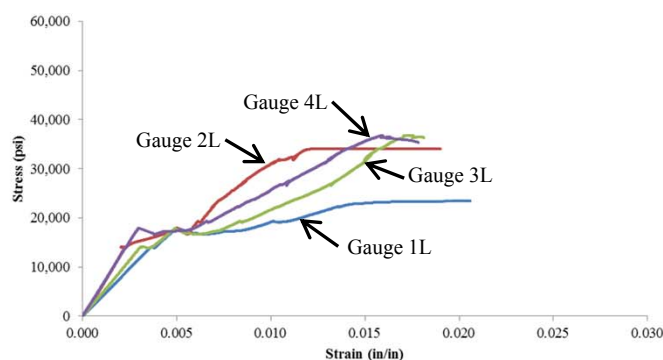


PICTURE OF SPECIMEN POST-TEST

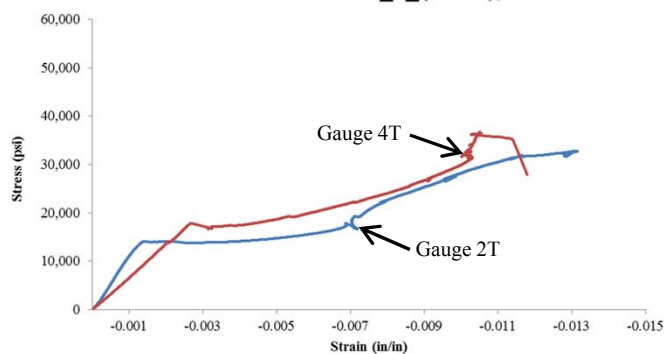


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | 0.0029 | 0.0010 | 3,891,911 | | | | |
| 2L | 0.0018 | 0.0007 | 6,346,104 | 2T | -0.0010 | -0.0004 | 0.5397 |
| 3L | 0.0024 | 0.0008 | 4,568,765 | | | | |
| 4L | 0.0018 | 0.0006 | 6,167,136 | 4T | -0.0016 | -0.0006 | 0.8934 |
| Average | | | 5,243,479 | | | | 0.7165 |

Stress-Strain Curve 140_3_(09-06), Long.



Stress-Strain Curve 140_3_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-4-140-FY09**
 Test Date: 10/27/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , ν_{xy}

Average Material Properties:

Ultimate Load, P_x : 11,907 lbs
 Tensile Strength, ST_x : 37,209 psi
 Tensile Modulus, E_x : 5,113,242 psi
 Ultimate Strain, ϵ_x : 0.0073 in/in
 Poisson's Ratio, ν_{xy} : 1.0903

Measured Specimen Dimensions:

Width, W: 0.4000 in
 Thickness, H: 0.8000 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,191 lbs
 30% Max Load: 3,572 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

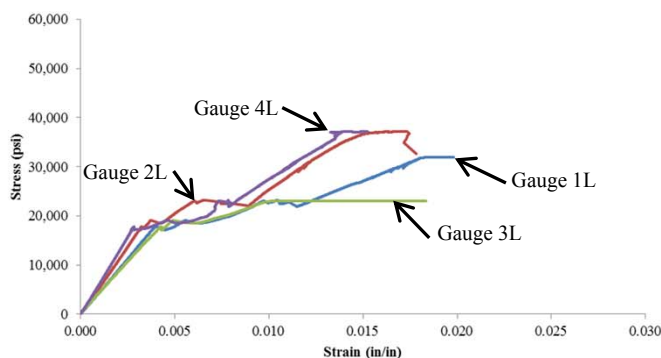


PICTURE OF SPECIMEN POST-TEST

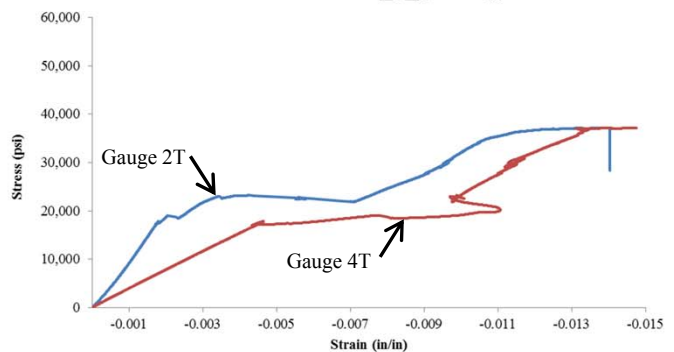


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | 0.0025 | 0.0008 | 4,511,769 | | | | |
| 2L | 0.0021 | 0.0007 | 5,436,876 | 2T | -0.0012 | -0.0004 | 0.5419 |
| 3L | 0.0026 | 0.0008 | 4,201,729 | | | | |
| 4L | 0.0018 | 0.0006 | 6,302,594 | 4T | -0.0029 | -0.0009 | 1.6387 |
| Average | | | 5,113,242 | | | | 1.0903 |

Stress-Strain Curve 140_4_(09-06), Long.



Stress-Strain Curve 140_4_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM D3039 / D3039M-08) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

Individual Specimen Test Summary

Specimen ID: **MAT6-TX-5-140-FY09**
 Test Date: 10/27/2011
 Specimen Received: 7/07/2011
 Properties Measured: ST_x , E_x , v_{xy}

Average Material Properties:

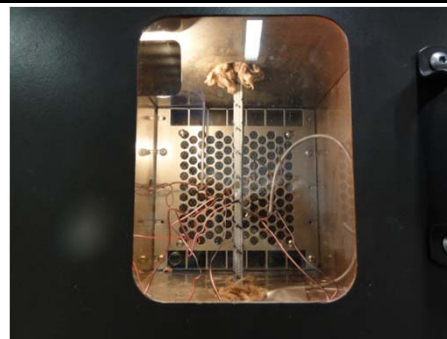
Ultimate Load, P_x : 11,700 lbs
 Tensile Strength, ST_x : 33,527 psi
 Tensile Modulus, E_x : 5,536,273 psi
 Ultimate Strain, ϵ_x : 0.0061 in/in
 Poisson's Ratio, v_{xy} : 0.7619

Measured Specimen Dimensions:

Width, W: 0.4230 in
 Thickness, H: 0.8250 in
 Laboratory Temperature: 68°F
 Failure Mode: AGM
 10% Max Load: 1,170 lbs
 30% Max Load: 3,510 lbs

INDIVIDUAL STRAIN GAUGE RESULTS

PICTURE OF SPECIMEN PRE-TEST

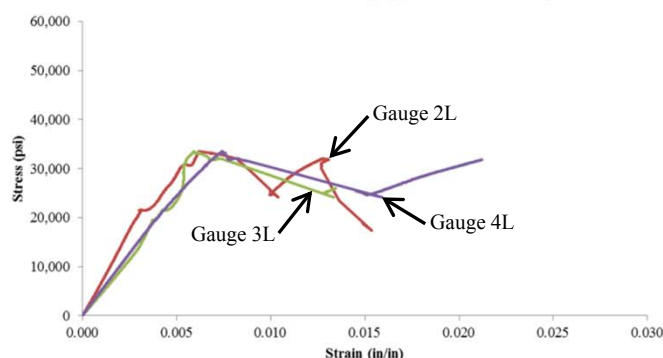


PICTURE OF SPECIMEN POST-TEST

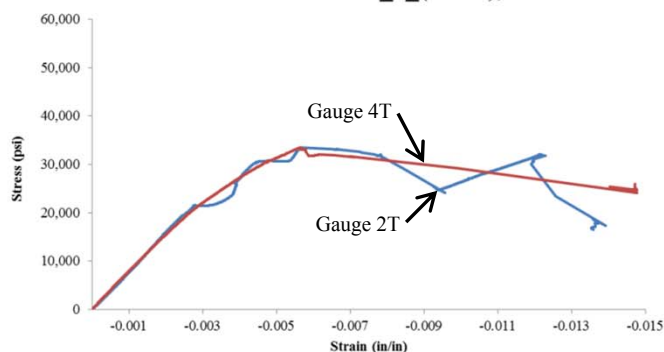


| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---------------------------------------|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Tensile Modulus, E_{xy} (psi) | Gauge | Strain @ 30% Max Load (in/in) | Strain @ 10% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | LOST | GAUGE | LOST | | | | |
| 2L | 0.0015 | 0.0005 | 6,951,723 | 2T | -0.0013 | -0.0005 | 0.8779 |
| 3L | 0.0022 | 0.0008 | 4,596,967 | | | | |
| 4L | 0.0020 | 0.0007 | 5,060,130 | 4T | -0.0013 | -0.0004 | 0.6458 |
| Average | | | 5,536,273 | | | | 0.7619 |

Stress-Strain Curve 140_5_(09-06), Long.



Stress-Strain Curve 140_5_(09-06), Lat.



Engineering Test notes:

- *The failure is classified as AGM for angled failure in the gauge area.
- *Specimen was fitted with one Vishay 20CBW strain gauge and three 125LT strain gauges
- *Modulus and Poisson's ratio was calculated using strain at 10% and 30% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTMD6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-CX-N40-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: -40°F

Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_x : 34,302 lbs
 Compressive Strength, SC_x : 41,637 psi
 Compressive Modulus, E_x : 4,367,710 psi
 Ultimate Strain, ϵ_x : 0.010 in/in
 Poisson's Ratio, ν_{xy} : 0.360

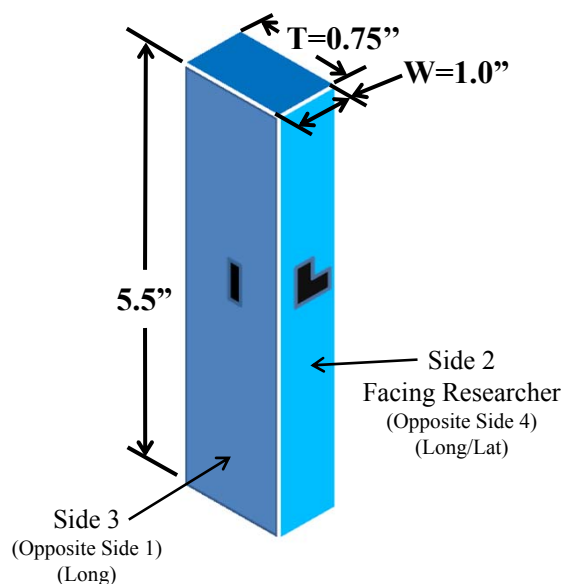
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|---------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT6-CX-01-N40-FY09 | 35,025 | 41,240 | 4,601,500 | 0.0092 | 0.321 | Delamination |
| MAT6-CX-02-N40-FY09 | 34,288 | 40,862 | 5,254,280 | 0.0085 | 0.222 | Delamination |
| MAT6-CX-03-N40-FY09 | 34,153 | 42,400 | 3,533,083 | 0.0124 | 0.513 | Delamination |
| MAT6-CX-04-N40-FY09 | 36,551 | 44,499 | 4,095,616 | 0.0115 | 0.433 | Delamination |
| MAT6-CX-05-N40-FY09 | 31,493 | 39,186 | 4,354,072 | 0.0092 | 0.312 | Delamination |
| Average | 34,302 | 41,637 | 4,367,710 | 0.0102 | 0.360 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

-40°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See I-20 to I-24 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-01-N40-FY09**
 Test Date: 8/19/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 35,025 lbs
 Compressive Strength, SC_x : 41,240 psi
 Compressive Modulus, E_x : 4,601,500 psi
 Ultimate Strain, ϵ_x : 0.0092 in/in
 Poisson's Ratio, v_{xy} : 0.321

Measured Specimen Dimensions:

Width, W : 1.0369 in
 Thickness, H : 0.8191 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,005 lbs
 50% Max Load: 17,512 lbs

PICTURE OF SPECIMEN PRE-TEST



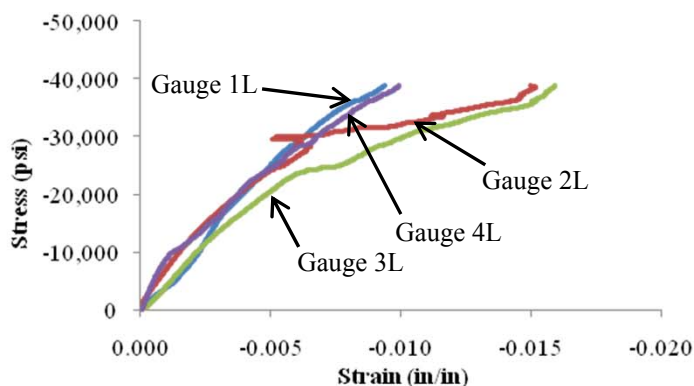
PICTURE OF SPECIMEN POST-TEST



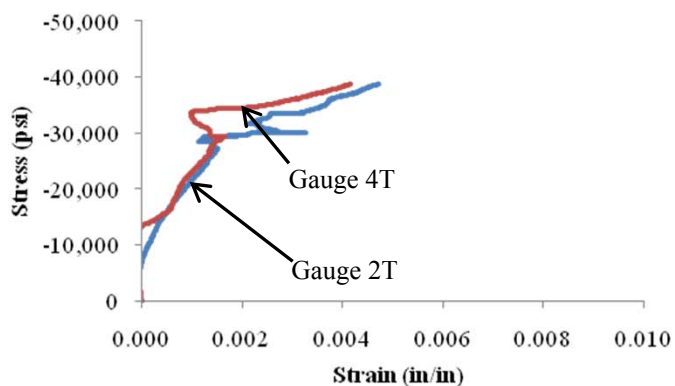
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00403 | -0.00195 | 5,932,702 | | | | |
| 2L | -0.00393 | -0.00118 | 4,492,574 | 2T | 0.00091 | -0.0002 | 0.314 |
| 3L | -0.00503 | -0.00179 | 3,817,680 | | | | |
| 4L | -0.00387 | -0.00089 | 4,163,045 | 4T | 0.00078 | 0.0007 | 0.328 |
| Average | | | 4,601,500 | | | | 0.321 |

Stress-Strain Curve N40F_01_(09-06)_Long



Stress-Strain Curve N40F_01_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT4-CX-02-N40-FY09**
 Test Date: 8/22/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 34,288 lbs
 Compressive Strength, SC_x : 40,862 psi
 Compressive Modulus, E_x : 5,254,280 psi
 Ultimate Strain, ϵ_x : 0.0085 in/in
 Poisson's Ratio, ν_{xy} : 0.222

Measured Specimen Dimensions:

Width, W: 1.0371 in
 Thickness, H: 0.8091 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,858 lbs
 50% Max Load: 17,144 lbs

PICTURE OF SPECIMEN PRE-TEST



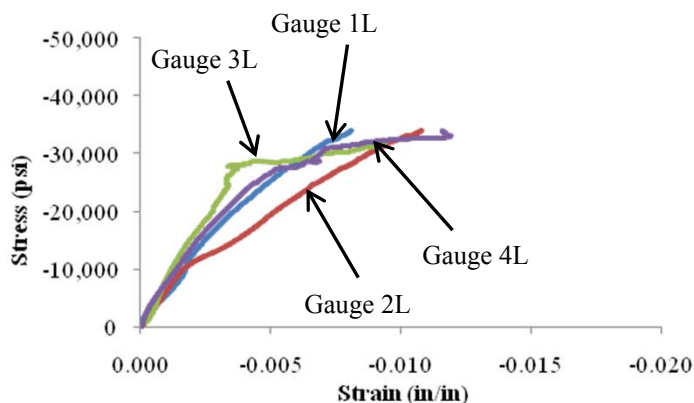
PICTURE OF SPECIMEN POST-TEST



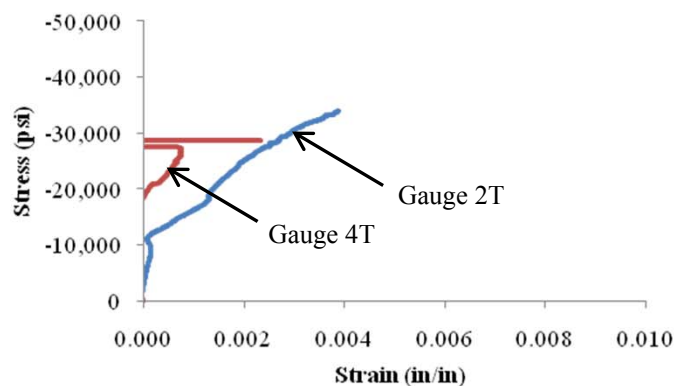
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------|-------------------------------|-------------------------------------|----------------|-------------------------------|-------------------------------|-----------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00369 | -0.00151 | 5,628,409 | | | | |
| 2L | -0.00530 | -0.00130 | 3,070,274 | 2T | 0.00142 | 0.00013 | 0.322 |
| 3L | -0.00278 | -0.00098 | 6,782,374 | | | | |
| 4L | -0.00330 | -0.00108 | 5,536,064 | 4T | 0.00013 | -0.00014 | 0.122 |
| Average | | | 5,254,280 | | | | 0.222 |

Stress-Strain Curve N40_02_(09-06)_Long



Stress-Strain Curve N40F_02_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-03-N40-FY09**
 Test Date: 8/22/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

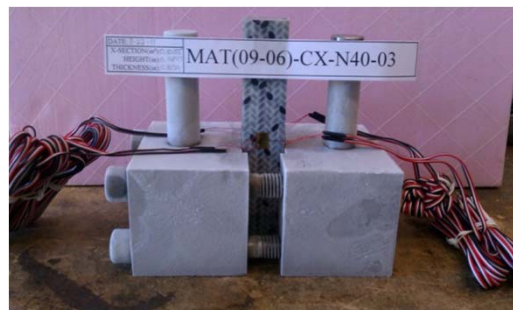
Average Material Properties:

Maximum Load, P_x : 34,153 lbs
 Compressive Strength, SC_x : 42,400 psi
 Compressive Modulus, E_x : 3,533,083 psi
 Ultimate Strain, ϵ_x : 0.0124 in/in
 Poisson's Ratio, v_{xy} : 0.513

Measured Specimen Dimensions:

Width, W: 0.9897 in
 Thickness, H: 0.8139 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,831 lbs
 50% Max Load: 17,076 lbs

PICTURE OF SPECIMEN PRE-TEST



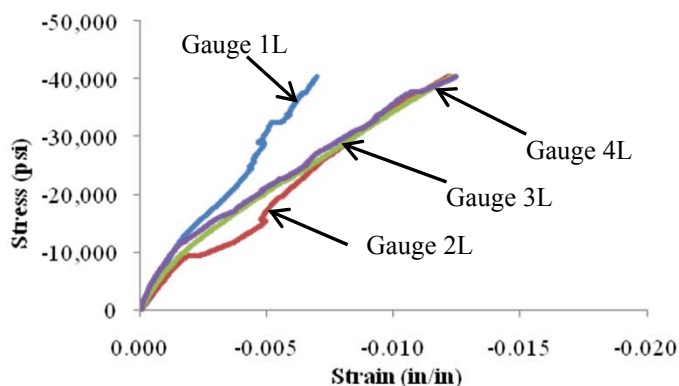
PICTURE OF SPECIMEN POST-TEST



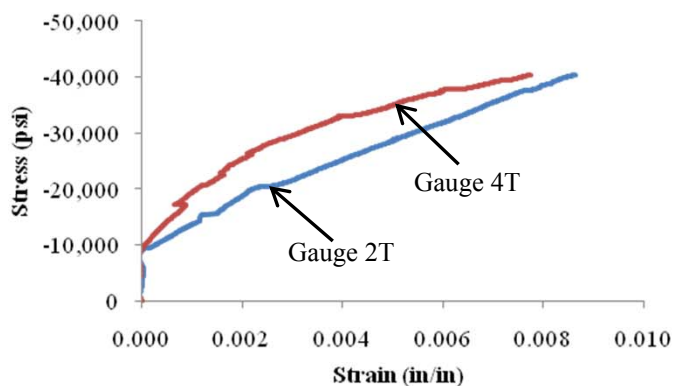
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00377 | -0.00109 | 4,744,127 | | | | |
| 2L | -0.00598 | -0.00159 | 2,895,919 | 2T | 0.00289 | -0.00004 | 0.667 |
| 3L | -0.00524 | -0.00137 | 3,289,024 | | | | |
| 4L | -0.00498 | -0.00101 | 3,203,263 | 4T | 0.00138 | -0.00005 | 0.360 |
| Average | | | 3,533,083 | | | | 0.513 |

Stress-Strain Curve N40_03_(09-06)_Long



Stress-Strain Curve N40_03_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-04-N40-FY09**
 Test Date: 8/22/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 36,551 lbs
 Compressive Strength, SC_x : 44,499 psi
 Compressive Modulus, E_x : 4,095,616 psi
 Ultimate Strain, ϵ_x : 0.0115 in/in
 Poisson's Ratio, v_{xy} : 0.433

Measured Specimen Dimensions:

Width, W: 1.0355 in
 Thickness, H: 0.7932 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 7,310 lbs
 50% Max Load: 18,276 lbs

PICTURE OF SPECIMEN PRE-TEST



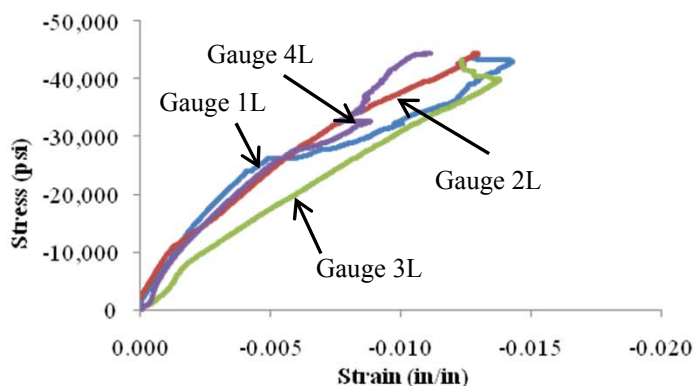
PICTURE OF SPECIMEN POST-TEST



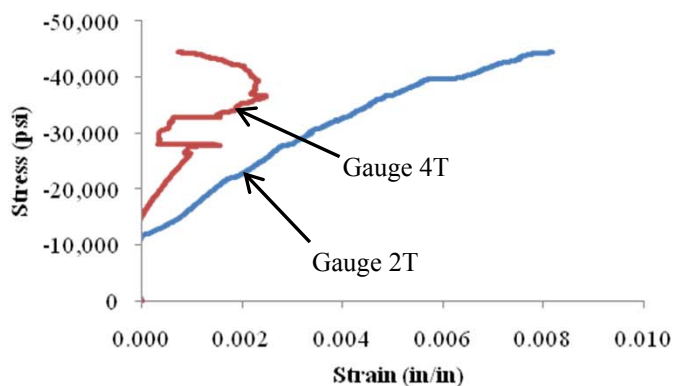
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00370 | -0.00117 | 5,287,034 | | | | |
| 2L | -0.00447 | -0.00092 | 3,753,308 | 2T | 0.00190 | -0.00017 | 0.582 |
| 3L | -0.00675 | -0.00206 | 2,847,337 | | | | |
| 4L | -0.00423 | -0.00126 | 4,494,787 | 4T | 0.00057 | -0.00027 | 0.284 |
| Average | | | 4,095,616 | | | | 0.433 |

Stress-Strain Curve N40_04_(09-06)_Long



Stress-Strain Curve N40_04_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-05-N40-FY09**
 Test Date: 8/22/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 31,493 lbs
 Compressive Strength, SC_x : 39,186 psi
 Compressive Modulus, E_x : 4,354,072 psi
 Ultimate Strain, ϵ_x : 0.0092 in/in
 Poisson's Ratio, ν_{xy} : 0.312

Measured Specimen Dimensions:

Width, W : 1.0012 in
 Thickness, H : 0.8027 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 6,299 lbs
 50% Max Load: 15,747 lbs

PICTURE OF SPECIMEN PRE-TEST



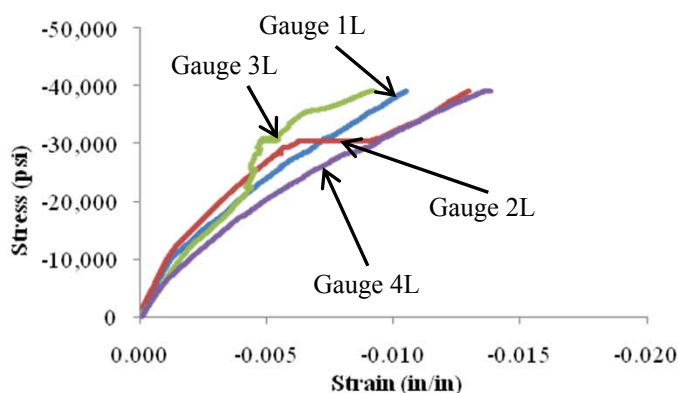
PICTURE OF SPECIMEN POST-TEST



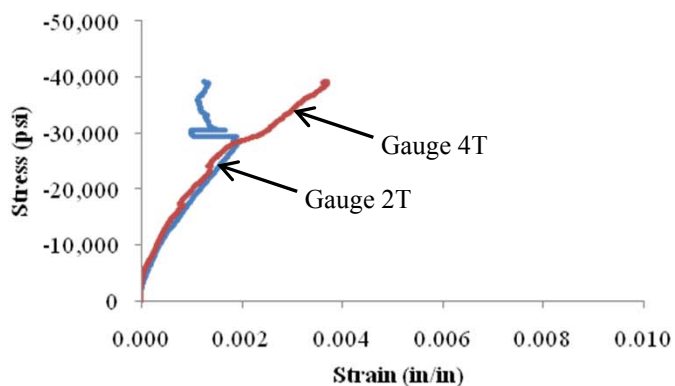
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00373 | -0.00091 | 4,169,791 | | | | |
| 2L | -0.00308 | -0.00080 | 5,140,204 | 2T | 0.00112 | 0.00023 | 0.389 |
| 3L | -0.00377 | -0.00121 | 4,592,985 | | | | |
| 4L | -0.00473 | -0.00139 | 3,513,310 | 4T | 0.00096 | 0.00018 | 0.235 |
| Average | | | 4,354,072 | | | | 0.312 |

Stress-Strain Curve N40_05_(09-06)_Long



Stress-Strain Curve N40_05_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-CX-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 70°F

Properties Measured: SC_x , E_x , ν_{xy}

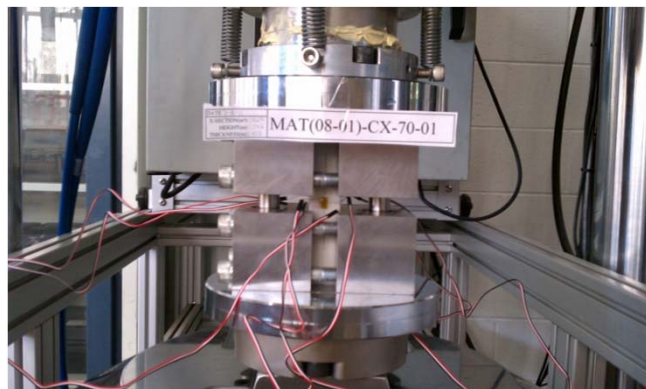
Average Material Properties (5 Specimens):

Ultimate Load, P_x : 21,965 lbs
 Compressive Strength, SC_x : 27,485 psi
 Compressive Modulus, E_x : 5,474,333 psi
 Ultimate Strain, ϵ_x : 0.005 in/in
 Poisson's Ratio, ν_{xy} : 0.388

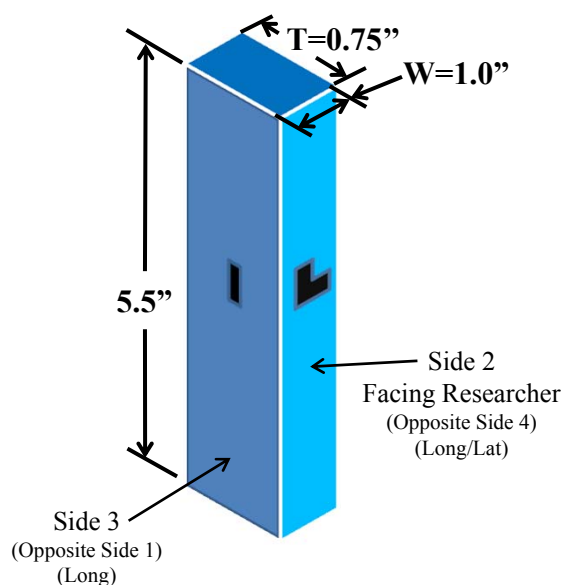
| Specimen | Max Load, P_x (lbs) | Compressive Strength, SC_x (psi) | Compressive Modulus, E_x (psi) | Ultimate Strain, ϵ_x (in/in) | Poisson's Ratio, ν_{xy} | Failure Mode |
|--------------------|-----------------------|------------------------------------|----------------------------------|---------------------------------------|-----------------------------|--------------|
| MAT6-CX-01-70-FY09 | 23,133 | 29,495 | 5,308,928 | 0.0057 | 0.619 | Delamination |
| MAT6-CX-02-70-FY09 | 22,192 | 26,530 | 5,382,380 | 0.0051 | 0.240 | Delamination |
| MAT6-CX-03-70-FY09 | 22,984 | 29,573 | 5,592,650 | 0.0062 | 0.423 | Delamination |
| MAT6-CX-04-70-FY09 | 20,146 | 25,654 | 5,092,536 | 0.0050 | 0.236 | Delamination |
| MAT6-CX-05-70-FY09 | 21,370 | 26,175 | 5,995,173 | 0.0050 | 0.420 | Delamination |
| Average | 21,965 | 27,485 | 5,474,333 | 0.0054 | 0.388 | |

Test Description:

The In-Plane Compression Test, performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

70°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See I-26 to I-30 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-01-70-FY09**
 Test Date: 8/19/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 23,133 lbs
 Compressive Strength, SC_x : 29,495 psi
 Compressive Modulus, E_x : 5,308,928 psi
 Ultimate Strain, ϵ_x : 0.0057 in/in
 Poisson's Ratio, ν_{xy} : 0.619

Measured Specimen Dimensions:

Width, W: 0.9849 in
 Thickness, H: 0.7963 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,627 lbs
 50% Max Load: 11,566 lbs

PICTURE OF SPECIMEN PRE-TEST



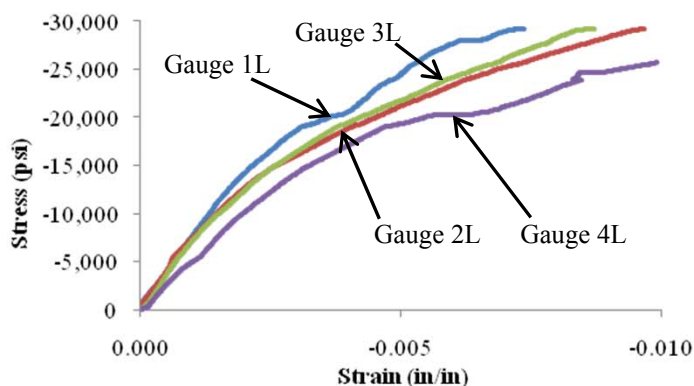
PICTURE OF SPECIMEN POST-TEST



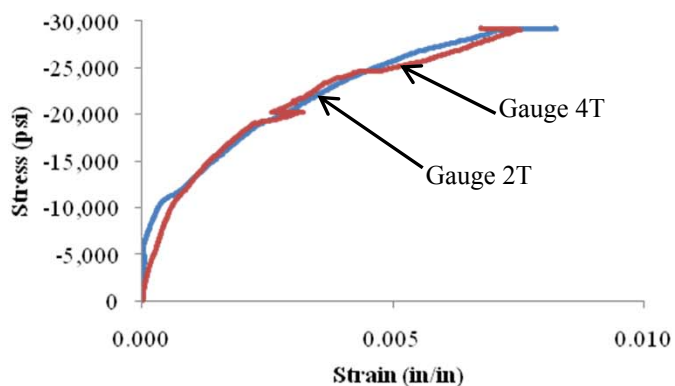
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00210 | -0.00076 | 6,600,330 | | | | |
| 2L | -0.00251 | -0.00070 | 4,900,446 | 2T | 0.00134 | 0.00003 | 0.729 |
| 3L | -0.00251 | -0.00080 | 5,165,476 | | | | |
| 4L | -0.00314 | -0.00120 | 4,569,459 | 4T | 0.00129 | 0.00030 | 0.510 |
| Average | | | 5,308,928 | | | | 0.619 |

Stress-Strain Curve 70F_01_(09-06)_Long



Stress-Strain Curve 70F_01_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-02-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 22,192 lbs
 Compressive Strength, SC_x : 26,530 psi
 Compressive Modulus, E_x : 5,382,380 psi
 Ultimate Strain, ϵ_x : 0.0051 in/in
 Poisson's Ratio, ν_{xy} : 0.240

Measured Specimen Dimensions:

Width, W : 1.0354 in
 Thickness, H : 0.8079 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,438 lbs
 50% Max Load: 11,096 lbs

PICTURE OF SPECIMEN PRE-TEST



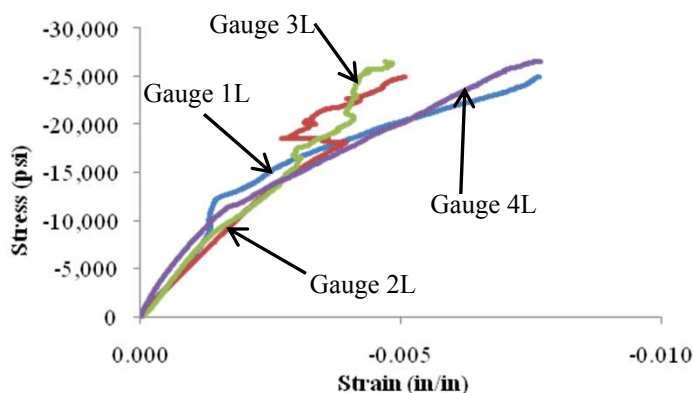
PICTURE OF SPECIMEN POST-TEST



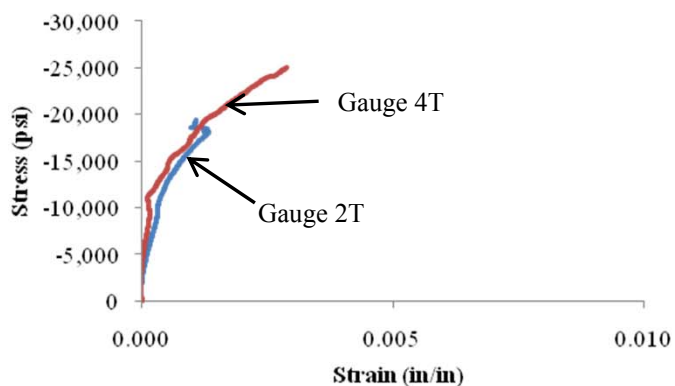
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00193 | -0.00086 | 7,413,493 | | | | |
| 2L | -0.00250 | -0.00094 | 5,076,911 | 2T | 0.00056 | 0.00003 | 0.282 |
| 3L | -0.00255 | -0.00081 | 4,559,183 | | | | |
| 4L | -0.00237 | -0.00060 | 4,479,933 | 4T | 0.00039 | 0.00039 | 0.198 |
| Average | | | 5,382,380 | | | | 0.240 |

Stress-Strain Curve 70F_02_(09-06)_Long



Stress-Strain Curve 70F_02_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-03-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

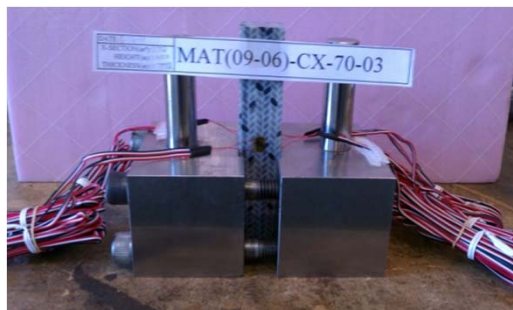
Average Material Properties:

Maximum Load, P_x : 22,984 lbs
 Compressive Strength, SC_x : 29,573 psi
 Compressive Modulus, E_x : 5,592,650 psi
 Ultimate Strain, ϵ_x : 0.0062 in/in
 Poisson's Ratio, ν_{xy} : 0.423

Measured Specimen Dimensions:

Width, W: 1.0050 in
 Thickness, H: 0.7733 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,597 lbs
 50% Max Load: 11,492 lbs

PICTURE OF SPECIMEN PRE-TEST



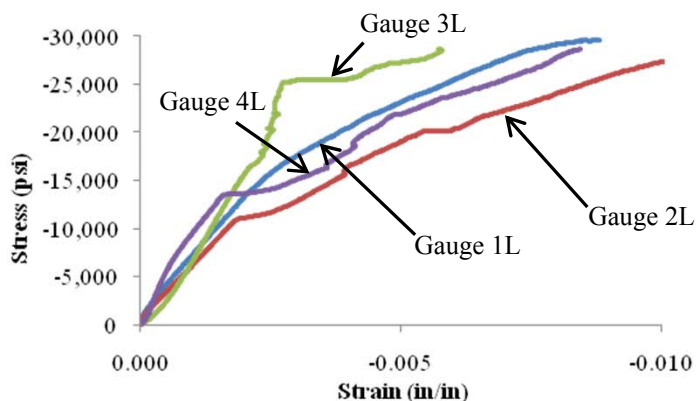
PICTURE OF SPECIMEN POST-TEST



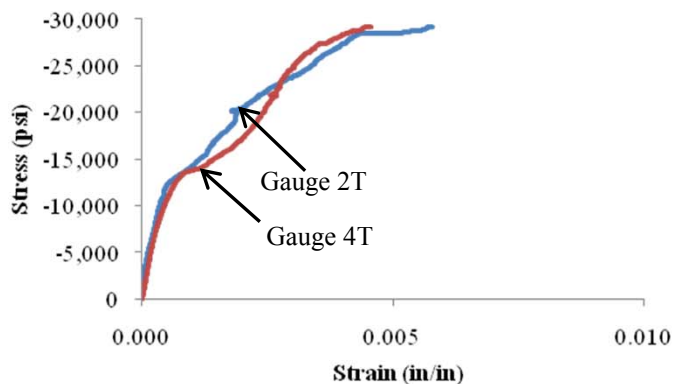
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00228 | -0.00077 | 5,884,318 | | | | |
| 2L | -0.00362 | -0.00094 | 3,313,422 | 2T | 0.00109 | 0.00017 | 0.346 |
| 3L | -0.00187 | -0.00092 | 9,302,826 | | | | |
| 4L | -0.00282 | -0.00053 | 3,870,035 | 4T | 0.00136 | 0.00021 | 0.201 |
| Average | | | 5,592,650 | | | | 0.423 |

Stress-Strain Curve 70F_03_(09-06)_Long



Stress-Strain Curve 70F_03_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-04-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 20,146 lbs
 Compressive Strength, SC_x : 25,654 psi
 Compressive Modulus, E_x : 5,092,536 psi
 Ultimate Strain, ϵ_x : 0.0050 in/in
 Poisson's Ratio, ν_{xy} : 0.236

Measured Specimen Dimensions:

Width, W: 0.9566 in
 Thickness, H: 0.8209 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,029 lbs
 50% Max Load: 10,073 lbs

PICTURE OF SPECIMEN PRE-TEST



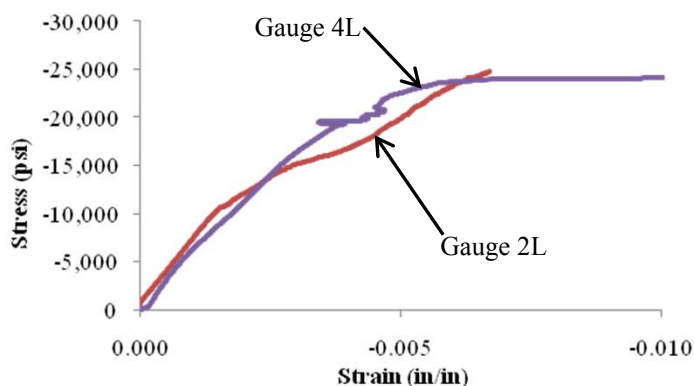
PICTURE OF SPECIMEN POST-TEST



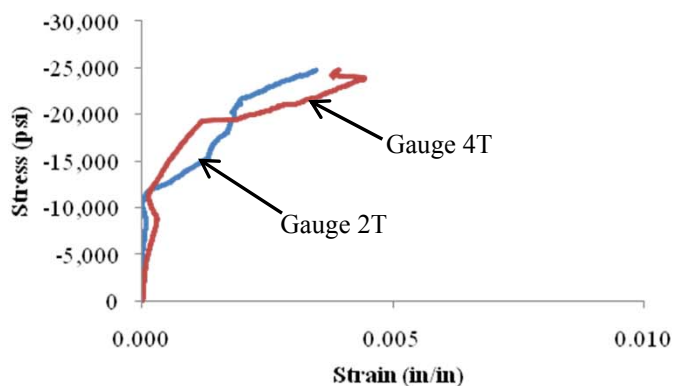
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | Lost Gauge | Lost Gauge | - | | | | |
| 2L | -0.00222 | -0.00066 | 4,961,017 | 2T | 0.00057 | 0.00001 | 0.362 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.00227 | -0.00080 | 5,224,055 | 4T | 0.00029 | 0.00013 | 0.111 |
| Average | | | 5,092,536 | | | | 0.236 |

Stress-Strain Curve 70F_04_(09-06)_Long



Stress-Strain Curve 70F_04_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-05-70-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , ν_{xy}

Average Material Properties:

Maximum Load, P_x : 21,370 lbs
 Compressive Strength, SC_x : 26,175 psi
 Compressive Modulus, E_x : 5,995,173 psi
 Ultimate Strain, ϵ_x : 0.0050 in/in
 Poisson's Ratio, ν_{xy} : 0.420

Measured Specimen Dimensions:

Width, W: 0.9953 in
 Thickness, H: 0.8203 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 4,274 lbs
 50% Max Load: 10,685 lbs

PICTURE OF SPECIMEN PRE-TEST



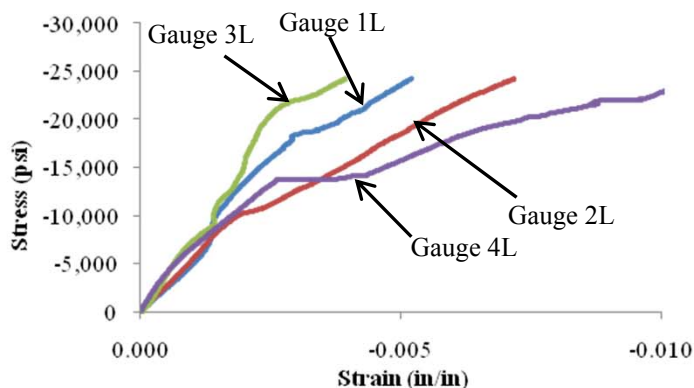
PICTURE OF SPECIMEN POST-TEST



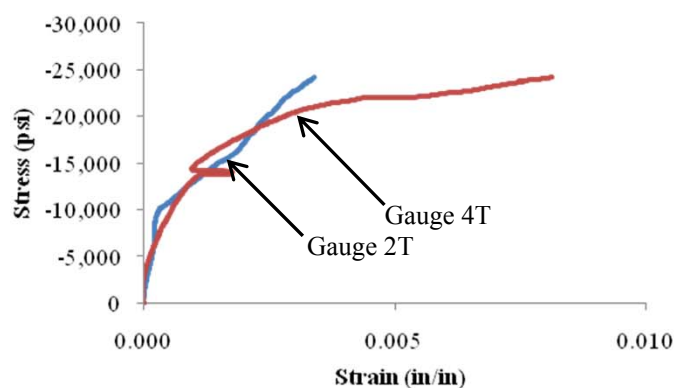
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|-----------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, ν_{xy} |
| 1L | -0.00192 | -0.00106 | 9,062,672 | | | | |
| 2L | -0.00321 | -0.00096 | 3,489,019 | 2T | 0.00102 | 0.00017 | 0.376 |
| 3L | -0.00179 | -0.00066 | 6,972,410 | | | | |
| 4L | -0.00247 | -0.00070 | 4,456,592 | 4T | 0.00095 | 0.00014 | 0.465 |
| Average | | | 5,995,173 | | | | 0.420 |

Stress-Strain Curve 70F_05_(09-06)_Long



Stress-Strain Curve 70F_05_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- In-Plane Compression Test

TEST: (ASTM6641/D6641 M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates Using a Combined Loading Compression (CLC) Test Fixture

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-CX-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**
 Nominal Temperature: **140°F**
 Properties Measured: **SC_x, E_x, v_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_x: **10,211** **lbs**
 Compressive Strength, SC_x: **12,922** **psi**
 Compressive Modulus, E_x: **5,593,651** **psi**
 Ultimate Strain, ε_x: **0.003** **in/in**
 Poisson's Ratio, v_{xy}: **0.400**

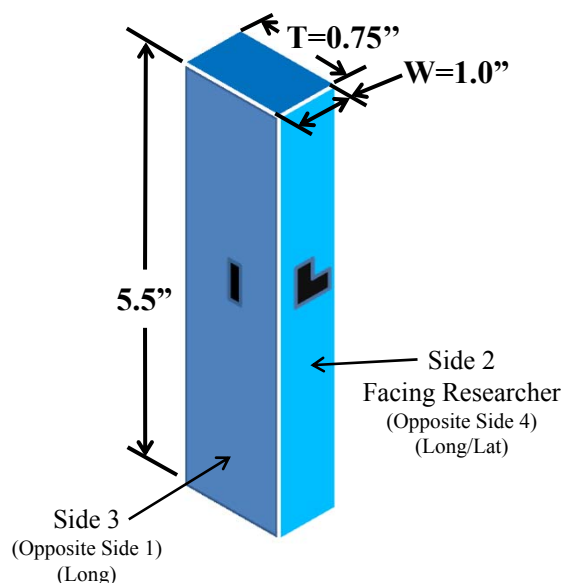
| Specimen | Max Load, P _x (lbs) | Compressive Strength, SC _x (psi) | Compressive Modulus, E _x (psi) | Ultimate Strain, ε _x (in/in) | Poisson's Ratio, v _{xy} | Failure Mode |
|---------------------|-----------------------------------|--|--|--|----------------------------------|--------------|
| MAT6-CX-01-140-FY09 | 10,806 | 13,217 | 6,342,811 | 0.0022 | 0.616 | Delamination |
| MAT6-CX-02-140-FY09 | 9,431 | 11,809 | 6,501,345 | 0.0020 | 0.211 | Delamination |
| MAT6 CX-03-140-FY09 | 11,152 | 14,555 | 5,291,246 | 0.0030 | 0.334 | Delamination |
| MAT6-CX-04-140-FY09 | 9,840 | 12,521 | 4,201,343 | 0.0034 | 0.411 | Delamination |
| MAT6-CX-05-140-FY09 | 9,824 | 12,507 | 5,631,510 | 0.0033 | 0.428 | Delamination |
| Average | 10,211 | 12,922 | 5,593,651 | 0.0028 | 0.400 | |

Test Description:

The In-Plane Compression Test performed within the guidelines of ASTM D6641, measures the in-plane compressive strength, compressive modulus and in-plane Poisson Ratio of fiber reinforced polymer matrix composite materials. In this test, one fiber orientation is vertical and one fiber orientation is along the thickness. A compressive force is applied axially at a rate of 0.05 in/min along the fibers 'x' or 'y' axis. Since the fibers are orientated at 0 and 90 degrees the 'x' and 'y' properties are assumed to be theoretically identical. The test is performed on the MTS 311. Four longitudinal strain gauges are used, one on each side of the specimen (1L, 2L, 3L and 4L) as shown below. Two lateral strain gauges (2T and 4T) are placed on opposite sides of the specimen along the width.

140°F Temperature Test Condition**Notes:**

- 1) 5 specimens tested, group of 5 displayed with relevant data shown
- 2) See I-32 to I-36 for individual specimen results
- 3) The ultimate strain recorded above is calculated using the compressive modulus which is based on the 20-50% linear region of the stress-strain curve.

**Nominal Dimensions/
Strain Gauge Configuration**

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-01-140-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 10,806 lbs
 Compressive Strength, SC_x : 13,217 psi
 Compressive Modulus, E_x : 6,342,811 psi
 Ultimate Strain, ϵ_x : 0.0022 in/in
 Poisson's Ratio, v_{xy} : 0.616

Measured Specimen Dimensions:

Width, W: 0.9856 in
 Thickness, H: 0.8295 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,161 lbs
 50% Max Load: 5,403 lbs

PICTURE OF SPECIMEN PRE-TEST



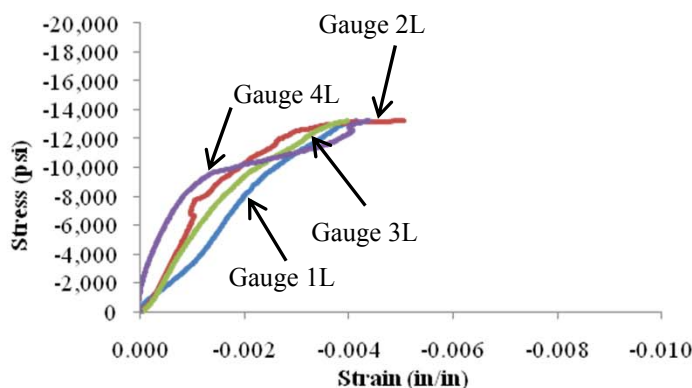
PICTURE OF SPECIMEN POST-TEST



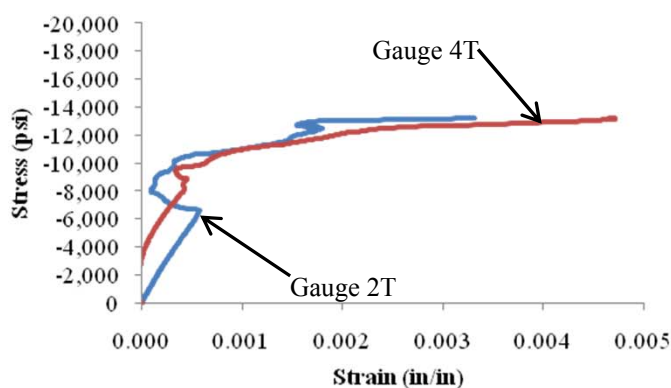
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00168 | -0.00078 | 4,409,532 | | | | |
| 2L | -0.00102 | -0.00049 | 7,374,049 | 2T | 0.00057 | 0.00021 | 0.677 |
| 3L | -0.00126 | -0.00053 | 5,443,188 | | | | |
| 4L | -0.00056 | -0.00008 | 8,144,472 | 4T | 0.00025 | 0.00002 | 0.555 |
| Average | | | 6,342,811 | | | | 0.616 |

Stress-Strain Curve 140F_01_(09-06)_Long



Stress-Strain Curve 140F_01_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-02-140-FY09**
 Test Date: 8/16/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 9,431 lbs
 Compressive Strength, SC_x : 11,809 psi
 Compressive Modulus, E_x : 6,501,345 psi
 Ultimate Strain, ϵ_x : 0.0020 in/in
 Poisson's Ratio, v_{xy} : 0.211

Measured Specimen Dimensions:

Width, W: 0.9879 in
 Thickness, H: 0.8084 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,886 lbs
 50% Max Load: 4,715 lbs

PICTURE OF SPECIMEN PRE-TEST



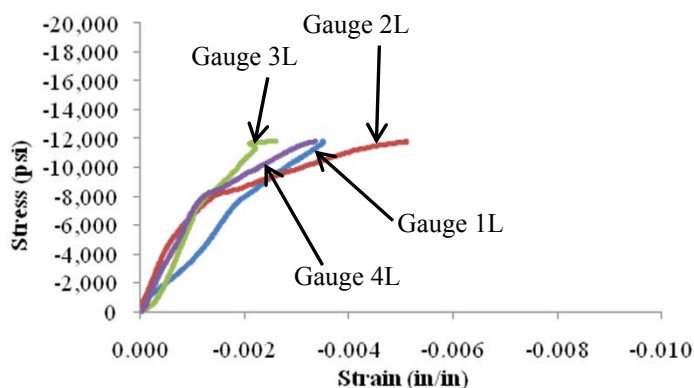
PICTURE OF SPECIMEN POST-TEST



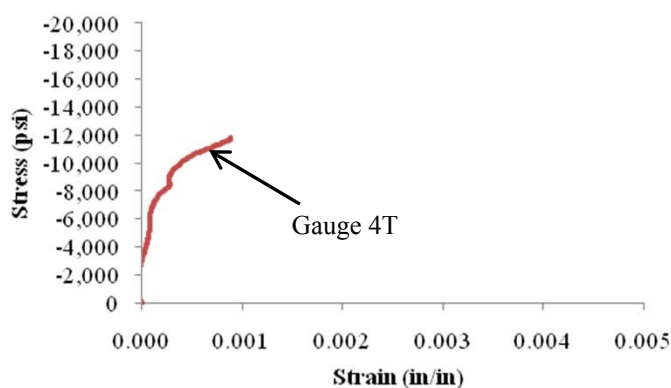
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00150 | -0.00061 | 3,988,283 | | | | |
| 2L | -0.00079 | -0.00025 | 6,544,531 | 2T | Lost Gauge | Lost Gauge | - |
| 3L | -0.00094 | -0.00052 | 8,629,514 | | | | |
| 4L | -0.00085 | -0.00033 | 6,843,053 | 4T | 0.00008 | -0.00003 | 0.211 |
| Average | | | 6,501,345 | | | | 0.211 |

Stress-Strain Curve 140F_02_(09-06)_Long



Stress-Strain Curve 140F_02_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT-CX-03-140-FY09**
 Test Date: 8/17/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 11,152 lbs
 Compressive Strength, SC_x : 14,555 psi
 Compressive Modulus, E_x : 5,291,246 psi
 Ultimate Strain, ϵ_x : 0.0030 in/in
 Poisson's Ratio, v_{xy} : 0.334

Measured Specimen Dimensions:

Width, W : 0.9615 in
 Thickness, H : 0.7969 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 2,230 lbs
 50% Max Load: 5,576 lbs

PICTURE OF SPECIMEN PRE-TEST



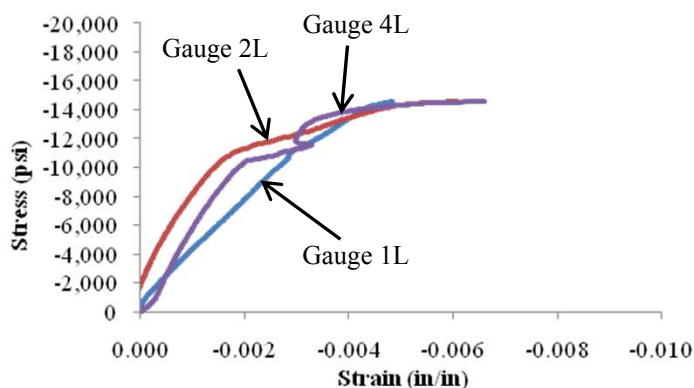
PICTURE OF SPECIMEN POST-TEST



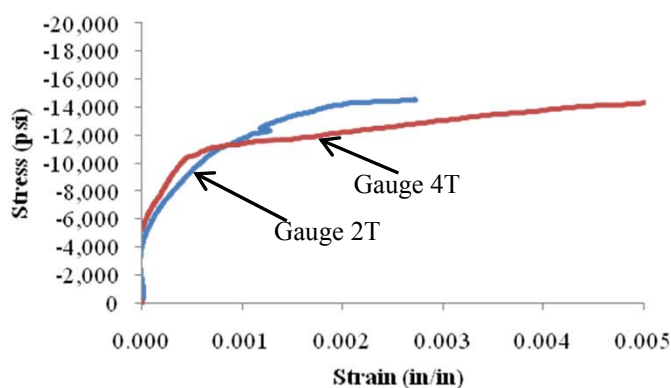
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00185 | -0.00060 | 3,478,782 | | | | |
| 2L | -0.00082 | -0.00013 | 6,309,288 | 2T | 0.00023 | -0.00002 | 0.353 |
| 3L | Lost Gauge | Lost Gauge | - | | | | |
| 4L | -0.00126 | -0.00055 | 6,085,667 | 4T | 0.00014 | -0.00009 | 0.316 |
| Average | | | 5,291,246 | | | | 0.334 |

Stress-Strain Curve 140F_03_(09-06)_Long



Stress-Strain Curve 140F_03_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-04-140-FY09**
 Test Date: 8/17/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 9,840 lbs
 Compressive Strength, SC_x : 12,521 psi
 Compressive Modulus, E_x : 4,201,343 psi
 Ultimate Strain, ϵ_x : 0.0034 in/in
 Poisson's Ratio, v_{xy} : 0.411

Measured Specimen Dimensions:

Width, W: 0.9856 in
 Thickness, H: 0.7974 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,968 lbs
 50% Max Load: 4,920 lbs

PICTURE OF SPECIMEN PRE-TEST



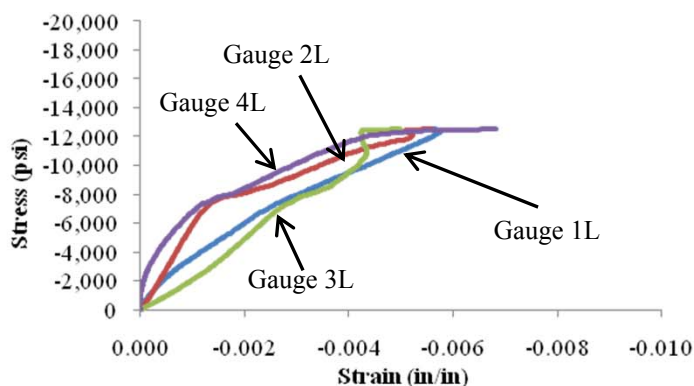
PICTURE OF SPECIMEN POST-TEST



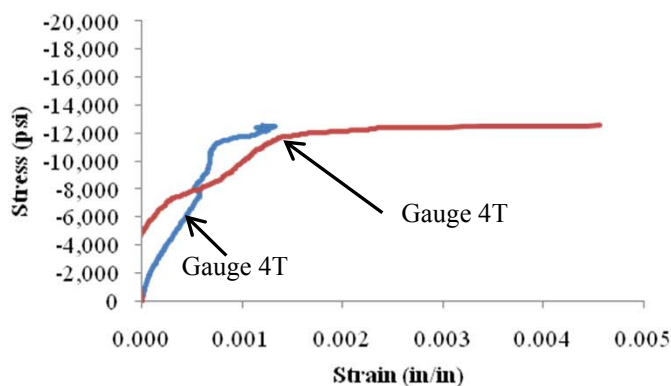
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00209 | -0.00058 | 2,485,457 | | | | |
| 2L | -0.00106 | -0.00045 | 6,082,060 | 2T | 0.00046 | 0.00012 | 0.547 |
| 3L | -0.00240 | -0.00118 | 3,068,102 | | | | |
| 4L | -0.00084 | -0.00011 | 5,169,751 | 4T | 0.00014 | -0.00006 | 0.276 |
| Average | | | 4,201,343 | | | | 0.411 |

Stress-Strain Curve 140F_04_(09-06)_Long



Stress-Strain Curve 140F_04_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: (ASTM6641/D6641M) Standard Test Method for Determining the Compressive Properties of Polymer Matrix Composite Laminates using a Combined Loading Compression (CLC) Test Fixture

Individual Specimen Test Summary

Specimen ID: **MAT6-CX-05-140-FY09**
 Test Date: 8/17/2011
 Specimen Received: 7/7/2011
 Properties Measured: SC_x , E_x , v_{xy}

Average Material Properties:

Maximum Load, P_x : 9,824 lbs
 Compressive Strength, SC_x : 12,507 psi
 Compressive Modulus, E_x : 5,631,510 psi
 Ultimate Strain, ϵ_x : 0.0023 in/in
 Poisson's Ratio, v_{xy} : 0.428

Measured Specimen Dimensions:

Width, W: 1.0130 in
 Thickness, H: 0.7754 in
 Laboratory Temperature: 70°F
 Failure Mode: Delamination
 20% Max Load: 1,965 lbs
 50% Max Load: 4,912 lbs

PICTURE OF SPECIMEN PRE-TEST



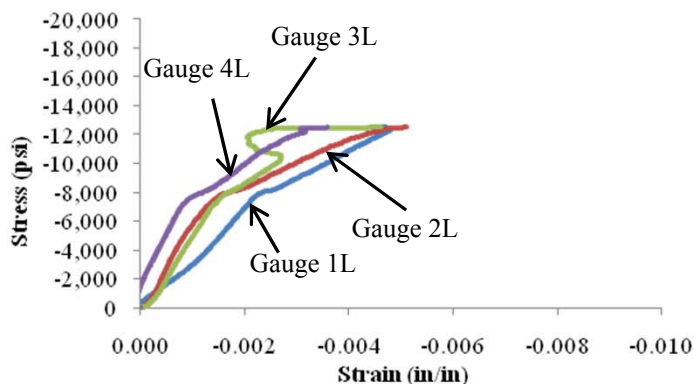
PICTURE OF SPECIMEN POST-TEST



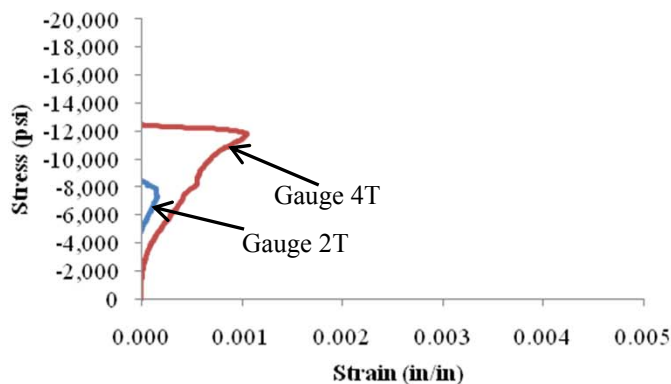
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | |
|---------------------|-------------------------------------|-------------------------------------|---|----------------|-------------------------------------|-------------------------------------|---------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Compressive Modulus, E_{xy} (psi) | Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Poisson's Ratio, v_{xy} |
| 1L | -0.00183 | -0.00083 | 3,741,819 | | | | |
| 2L | -0.00109 | -0.00047 | 6,004,314 | 2T | 0.00008 | -0.00012 | 0.318 |
| 3L | -0.00123 | -0.00058 | 5,801,922 | | | | |
| 4L | -0.00066 | -0.00012 | 6,977,987 | 4T | 0.00031 | 0.00002 | 0.538 |
| Average | | | 5,631,510 | | | | 0.428 |

Stress-Strain Curve 140F_05_(09-06)_Long



Stress-Strain Curve 140F_05_(09-06)_Lat



Engineering Test notes:

- *Specimen was fitted with four C2A-06-125-LT strain gauges
- *Compressive Modulus and Poisson's Ratio were calculated using strain at 20% and 50% of max load
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

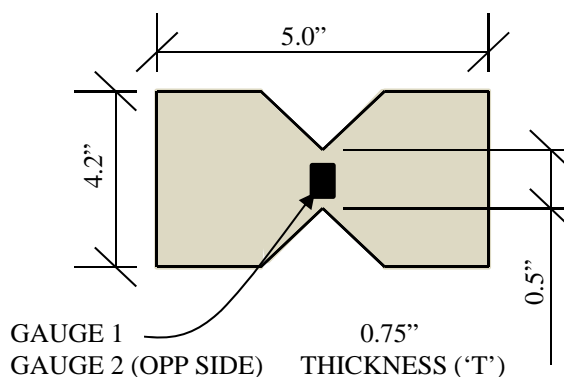
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-SXY-N40-FY09
Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric
Nominal Temperature: -40°F
Properties Measured: G_{xy} , S_{xy}
Average Material Properties (4 Specimens):
 Ultimate Load, P_{max} : 10,051 lbs
 Shear Strength, S_{xy} : 24,005 psi
 Shear Modulus, G_{xy} : 1,931,198 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT6-SXY-01-N40-FY09 | 9,898 | 22,755 | 1,915,809 | Shear |
| 2 | MAT6-SXY-02-N40-FY09 | 10,905 | 26,340 | 1,963,272 | Shear |
| 3 | MAT6-SXY-03-N40-FY09 | 9,645 | 23,698 | 2,011,342 | Shear |
| 4 | MAT6-SXY-04-N40-FY09 | 9,755 | 23,227 | 1,834,370 | Shear |
| Average | | 10,051 | 24,005 | 1,931,198 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS****Notes:**

- 1) Individual specimen results are shown on Sheets I-38 to I-41
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch
- 4) One specimen unavailable for testing. Therefore, only 4 specimens tested.

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-01-N40-FY09
 Test Date: 11/7/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,898 lbs
 Shear Strength, S_{xy} : 22,755 psi
 Shear Modulus, G_{xy} : 1,915,809 psi

Measured Specimen Dimensions:

Thickness, T: 0.7791 in
 Notch Length, N: 0.558 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,980 lbs
 50% Max Load: 4,949 lbs

PICTURE OF SPECIMEN PRE-TEST



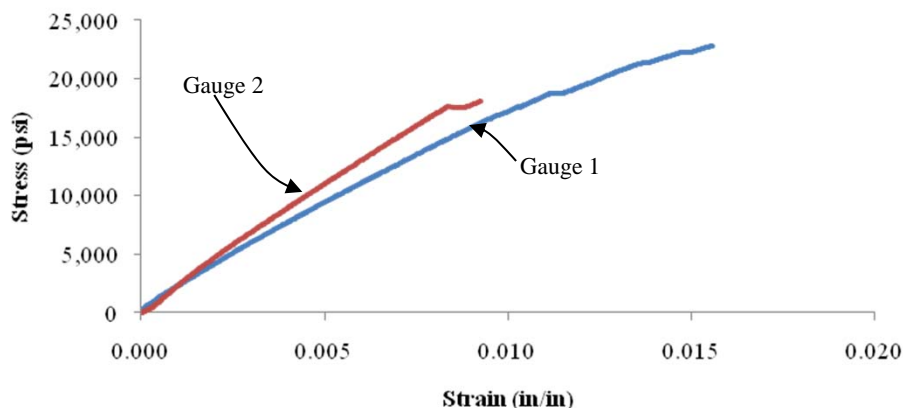
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00616 | 0.00220 | 1,723,278 |
| 2 | 0.00516 | 0.00192 | 2,108,340 |
| Average | | | 1,915,809 |

Stress-Strain Curve N40_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-02-N40-FY09
 Test Date: 11/8/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 10,905 lbs
 Shear Strength, S_{xy} : 26,340 psi
 Shear Modulus, G_{xy} : 1,963,272 psi

Measured Specimen Dimensions:

Thickness, T: 0.7589 in
 Notch Length, N: 0.546 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 2,181 lbs
 50% Max Load: 5,452 lbs

PICTURE OF SPECIMEN PRE-TEST



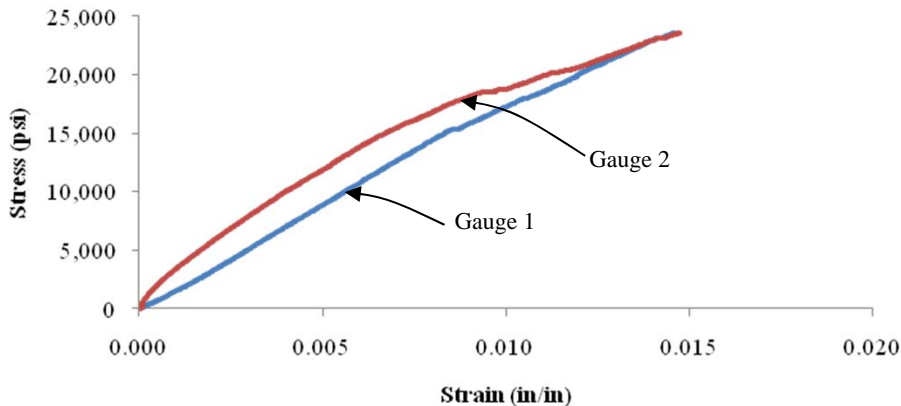
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00729 | 0.00308 | 1,877,276 |
| 2 | 0.00564 | 0.00179 | 2,049,268 |
| Average | | | 1,963,272 |

Stress-Strain Curve N40_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-03-N40-FY09
 Test Date: 11/10/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,645 lbs
 Shear Strength, S_{xy} : 23,698 psi
 Shear Modulus, G_{xy} : 2,011,342 psi

Measured Specimen Dimensions:

Thickness, T: 0.7688 in
 Notch Length, N: 0.529 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,929 lbs
 50% Max Load: 4,823 lbs

PICTURE OF SPECIMEN PRE-TEST



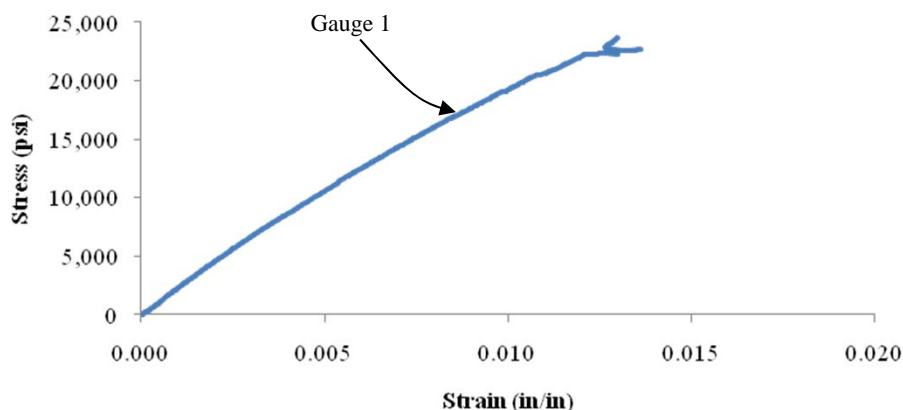
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00562 | 0.00209 | 2,011,342 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 2,011,342 |

Stress-Strain Curve N40_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)
- *Gauge 2 lost before 50% max load

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-04-N40-FY09
 Test Date: 11/10/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 9,755 lbs
 Shear Strength, S_{xy} : 23,227 psi
 Shear Modulus, G_{xy} : 1,834,370 psi

Measured Specimen Dimensions:

Thickness, T: 0.7818 in
 Notch Length, N: 0.537 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,951 lbs
 50% Max Load: 4,878 lbs

PICTURE OF SPECIMEN PRE-TEST



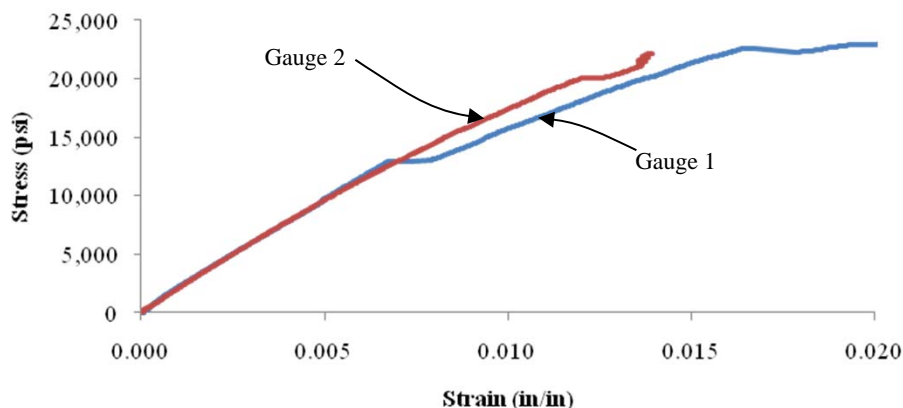
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00601 | 0.00227 | 1,865,370 |
| 2 | 0.00616 | 0.00230 | 1,803,525 |
| Average | | | 1,834,370 |

Stress-Strain Curve N40_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-SXY-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 70°F

Properties Measured: G_{xy} , S_{xy}

Average Material Properties (5 Specimens):

Ultimate Load, P_{max} : 7,567 lbs

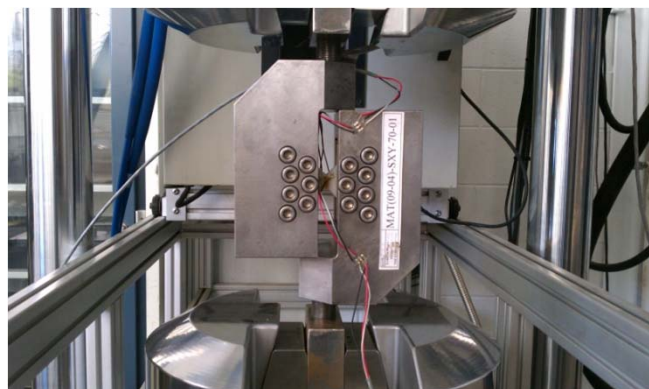
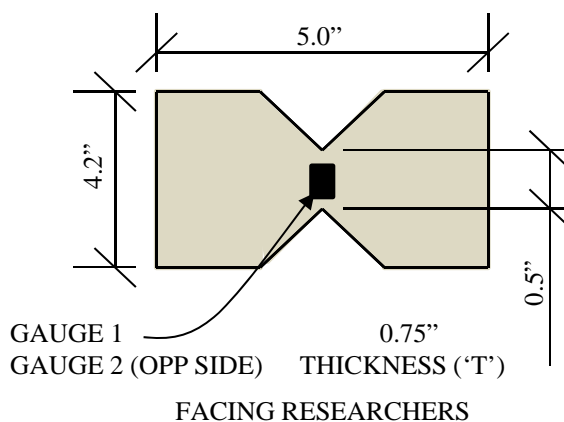
Shear Strength, S_{xy} : 18,541 psi

Shear Modulus, G_{xy} : 1,954,070 psi

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|---------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT6-SXY-01-70-FY09 | 7,671 | 18,663 | 1,843,230 | Shear |
| 2 | MAT6-SXY-02-70-FY09 | 7,296 | 18,379 | 1,619,536 | Shear |
| 3 | MAT6-SXY-03-70-FY09 | 7,808 | 18,860 | 1,981,445 | Shear |
| 4 | MAT6-SXY-04-70-FY09 | 7,357 | 18,768 | 2,208,611 | Shear |
| 5 | MAT6-SXY-05-70-FY09 | 7,701 | 18,035 | 2,117,530 | Shear |
| Average | | 7,567 | 18,541 | 1,954,070 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets I-44 to I-48
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-01-70-FY09
 Test Date: 11/1/2011
 Specimen Received: 8/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,671 lbs
 Shear Strength, S_{xy} : 18,663 psi
 Shear Modulus, G_{xy} : 1,843,230 psi

Measured Specimen Dimensions:

Thickness, T: 0.7666 in
 Notch Length, N: 0.536 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,534 lbs
 50% Max Load: 3,835 lbs

PICTURE OF SPECIMEN PRE-TEST



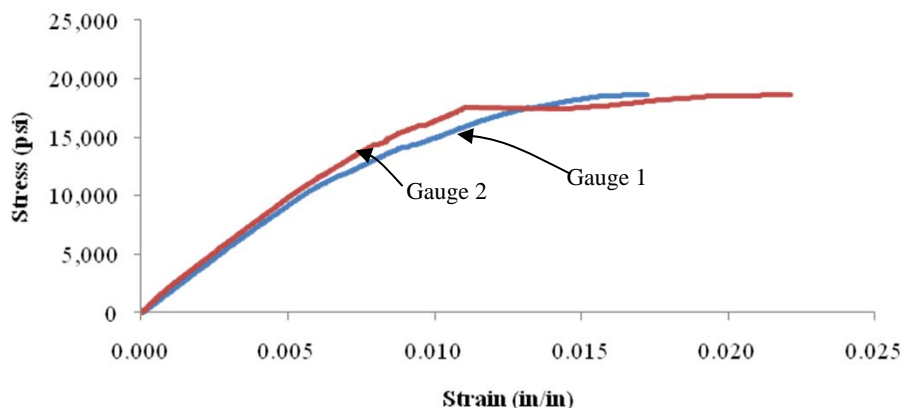
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00509 | 0.00200 | 1,809,033 |
| 2 | 0.00472 | 0.00174 | 1,877,427 |
| Average | | | 1,843,230 |

Stress-Strain Curve 70F_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-02-70-FY09
 Test Date: 11/2/2011
 Specimen Received: 8/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,296 lbs
 Shear Strength, S_{xy} : 18,379 psi
 Shear Modulus, G_{xy} : 1,619,536 psi

Measured Specimen Dimensions:

Thickness, T: 0.7781 in
 Notch Length, N: 0.510 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,459 lbs
 50% Max Load: 3,648 lbs

PICTURE OF SPECIMEN PRE-TEST



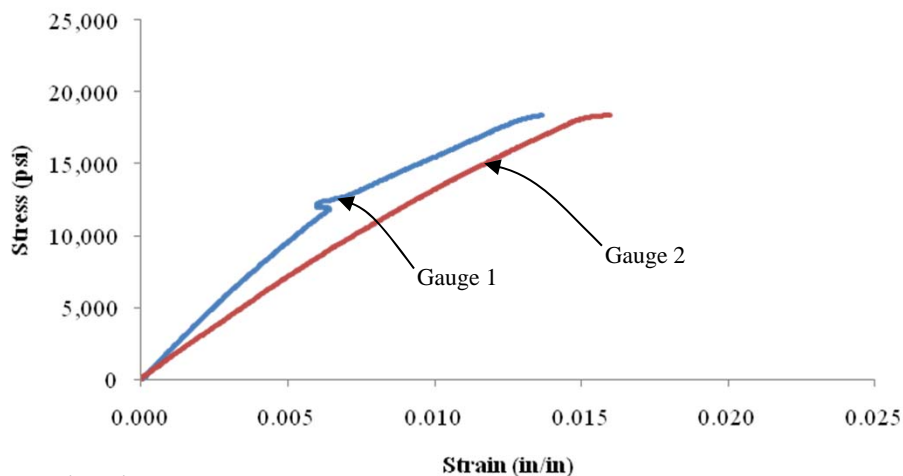
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00475 | 0.00179 | 1,864,126 |
| 2 | 0.00652 | 0.00251 | 1,374,946 |
| Average | | | 1,619,536 |

Stress-Strain Curve 70F_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-03-70-FY09
 Test Date: 11/3/2011
 Specimen Received: 8/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,808 lbs
 Shear Strength, S_{xy} : 18,860 psi
 Shear Modulus, G_{xy} : 1,981,445 psi

Measured Specimen Dimensions:

Thickness, T: 0.7877 in
 Notch Length, N: 0.525 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,562 lbs
 50% Max Load: 3,904 lbs

PICTURE OF SPECIMEN PRE-TEST



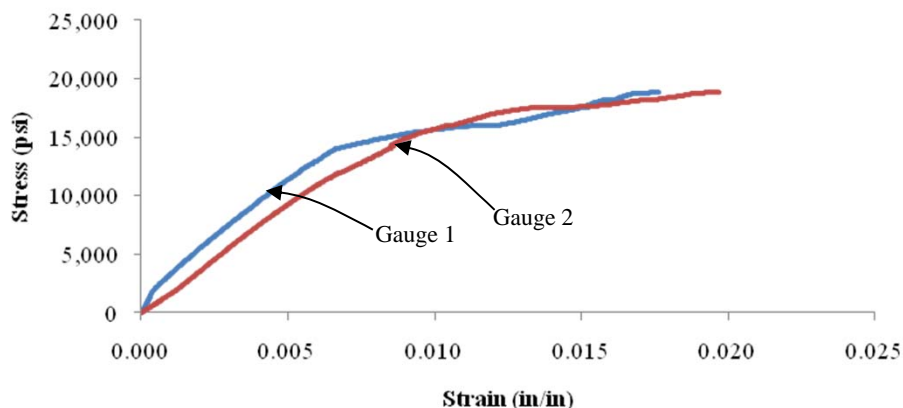
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00394 | 0.00120 | 2,060,859 |
| 2 | 0.00508 | 0.00210 | 1,902,030 |
| Average | | | 1,981,445 |

Stress-Strain Curve 70F_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-04-70-FY09
 Test Date: 11/3/2011
 Specimen Received: 8/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,357 lbs
 Shear Strength, S_{xy} : 18,768 psi
 Shear Modulus, G_{xy} : 2,208,611 psi

Measured Specimen Dimensions:

Thickness, T: 0.7721 in
 Notch Length, N: 0.508 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,471 lbs
 50% Max Load: 3,678 lbs

PICTURE OF SPECIMEN PRE-TEST



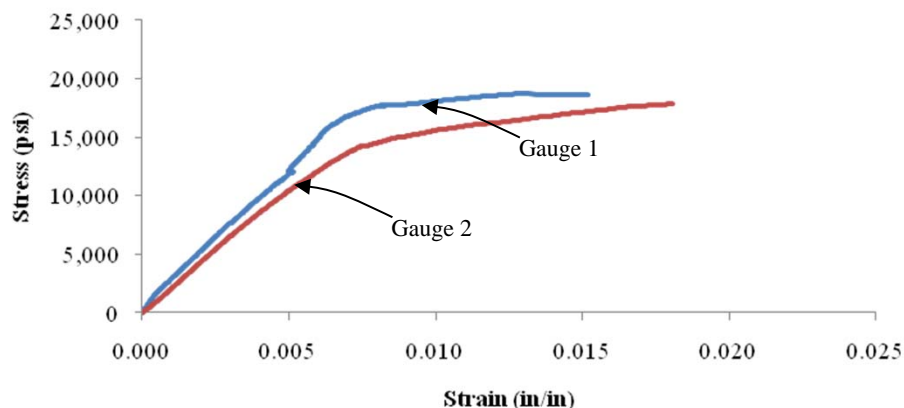
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00378 | 0.00135 | 2,319,042 |
| 2 | 0.00442 | 0.00173 | 2,098,181 |
| Average | | | 2,208,611 |

Stress-Strain Curve 70F_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-05-70-FY09
 Test Date: 11/4/2011
 Specimen Received: 8/31/2011
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 7,701 lbs
 Shear Strength, S_{xy} : 18,035 psi
 Shear Modulus, G_{xy} : 2,117,530 psi

Measured Specimen Dimensions:

Thickness, T: 0.7749 in
 Notch Length, N: 0.551 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,540 lbs
 50% Max Load: 3,850 lbs

PICTURE OF SPECIMEN PRE-TEST



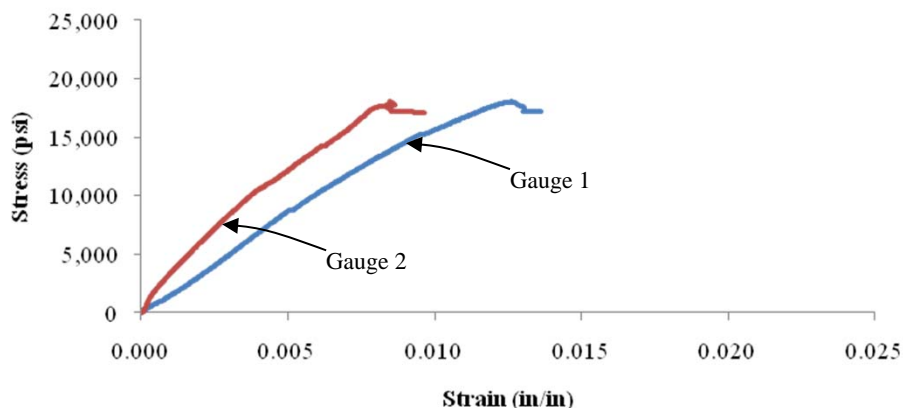
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00529 | 0.00225 | 1,780,547 |
| 2 | 0.00328 | 0.00108 | 2,454,514 |
| Average | | | 2,117,530 |

Stress-Strain Curve 70F_05_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method (ASTM D7078/ D7078M-05)

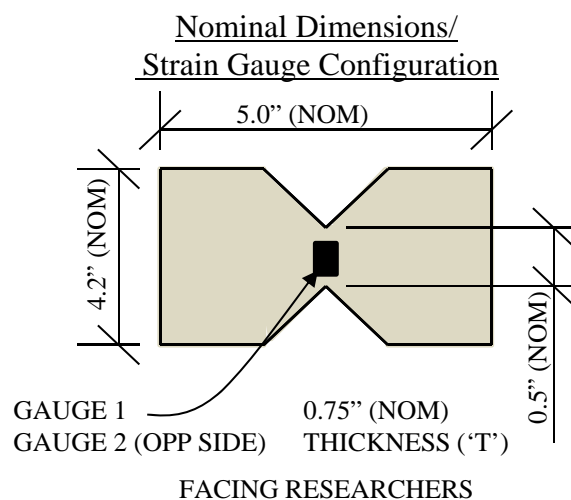
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-SXY-140-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**
 Nominal Temperature: **140°F**
 Properties Measured: **G_{xy} , S_{xy}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **5,027** **lbs**
 Shear Strength, S_{xy} : **11,769** **psi**
 Shear Modulus, G_{xy} : **1,567,885** **psi**

| Sample | Specimen | Max Load, P_{max} (lb) | Shear Strength, S_{xy} (psi) | Shear Modulus, G_{xy} (psi) | Failure Mode |
|----------------|----------------------|-----------------------------|-----------------------------------|----------------------------------|--------------|
| 1 | MAT6-SXY-01-140-FY09 | 5,509 | 12,811 | 1,578,446 | Shear |
| 2 | MAT6-SXY-02-140-FY09 | 4,420 | 10,068 | 1,294,187 | Shear |
| 3 | MAT6-SXY-03-140-FY09 | 5,283 | 12,700 | 1,914,566 | Shear |
| 4 | MAT6-SXY-04-140-FY09 | 4,772 | 11,610 | 1,650,074 | Shear |
| 5 | MAT6-SXY-05-140-FY09 | 5,151 | 11,654 | 1,402,153 | Shear |
| Average | | 5,027 | 11,769 | 1,567,885 | |

Test Description:

The V-Notch Rail Shear Test, performed within the guidelines of ASTM D7078 measures the shear strength and shear modulus of fiber reinforced polymer matrix composite materials. Fibers are oriented along the length of the specimen and along the width of the specimen as indicated below. The fiber grains are oriented in the 'x' and 'y' directions. The test is performed on the MTS 311. Two strain gauges are used, one on each side of the specimen at the center of the V-notch. The MTS hydraulic actuator applies the load to one fixture half which introduces a shear stress through the specimen. The shear stress is maximized at the notch. A test rate of 0.05 in/min is used.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets I-50 to E-54
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-01-140-FY09
 Test Date: 11/15/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 5,509 lbs
 Shear Strength, S_{xy} : 12,811 psi
 Shear Modulus, G_{xy} : 1,578,446 psi

Measured Specimen Dimensions:

Thickness, T: 0.7841 in
 Notch Length, N: 0.549 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,102 lbs
 50% Max Load: 2,754 lbs

PICTURE OF SPECIMEN PRE-TEST



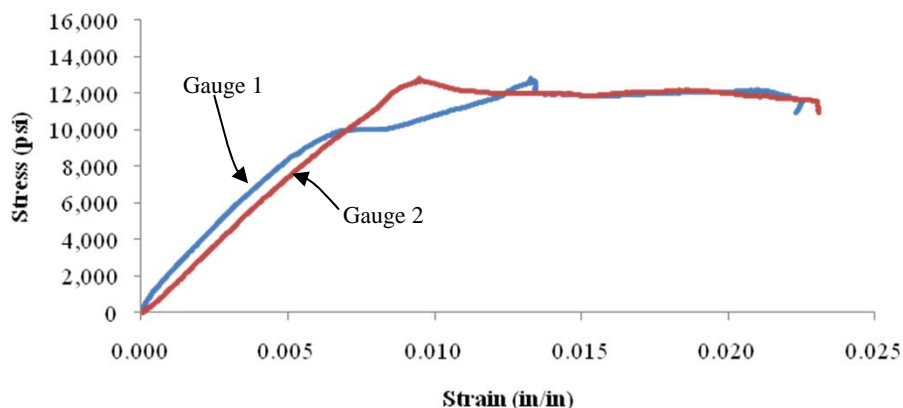
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00356 | 0.00118 | 1,616,796 |
| 2 | 0.00427 | 0.00177 | 1,540,096 |
| Average | | | 1,578,446 |

Stress-Strain Curve 140F_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-02-140-FY09
 Test Date: 11/15/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

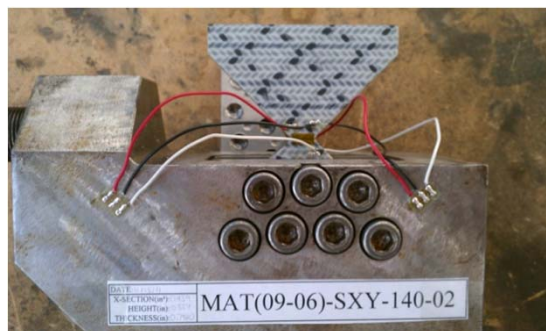
Average Material Properties:

Maximum Load, P_{max} : 4,420 lbs
 Shear Strength, S_{xy} : 10,068 psi
 Shear Modulus, G_{xy} : 1,294,187 psi

Measured Specimen Dimensions:

Thickness, T: 0.7920 in
 Notch Length, N: 0.554 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 884 lbs
 50% Max Load: 2,210 lbs

PICTURE OF SPECIMEN PRE-TEST



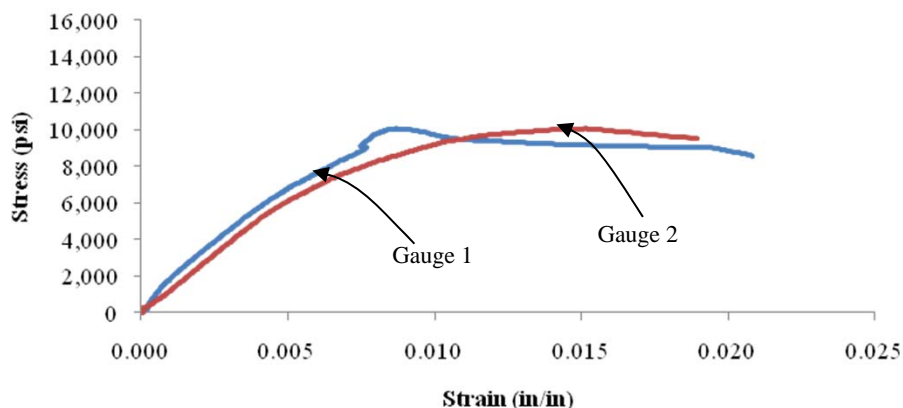
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00340 | 0.00109 | 1,305,650 |
| 2 | 0.00396 | 0.00160 | 1,282,725 |
| Average | | | 1,294,187 |

Stress-Strain Curve 140F_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-03-140-FY09
 Test Date: 11/16/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

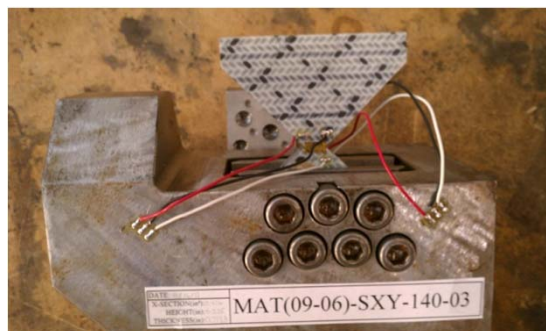
Average Material Properties:

Maximum Load, P_{max} : 5,283 lbs
 Shear Strength, S_{xy} : 12,700 psi
 Shear Modulus, G_{xy} : 1,914,566 psi

Measured Specimen Dimensions:

Thickness, T: 0.7773 in
 Notch Length, N: 0.535 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,057 lbs
 50% Max Load: 2,642 lbs

PICTURE OF SPECIMEN PRE-TEST



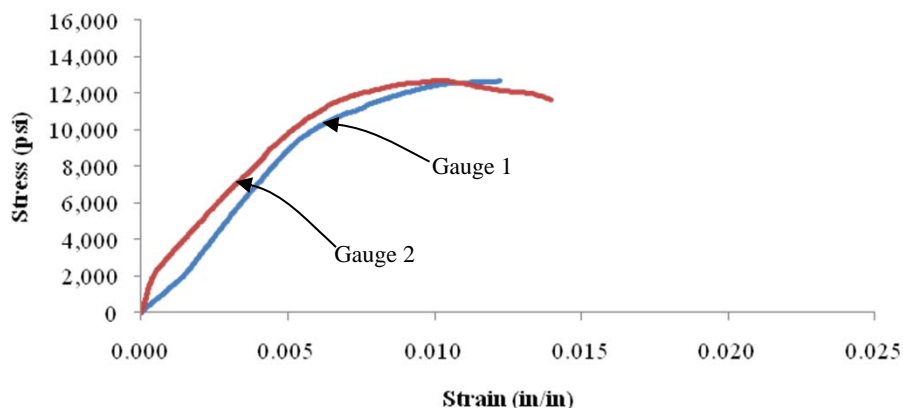
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00358 | 0.00172 | 2,052,156 |
| 2 | 0.00280 | 0.00065 | 1,776,977 |
| Average | | | 1,914,566 |

Stress-Strain Curve 140F_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-04-140-FY09
 Test Date: 11/16/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 4,772 lbs
 Shear Strength, S_{xy} : 11,610 psi
 Shear Modulus, G_{xy} : 1,650,074 psi

Measured Specimen Dimensions:

Thickness, T: 0.7751 in
 Notch Length, N: 0.530 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 954 lbs
 50% Max Load: 2,386 lbs

PICTURE OF SPECIMEN PRE-TEST



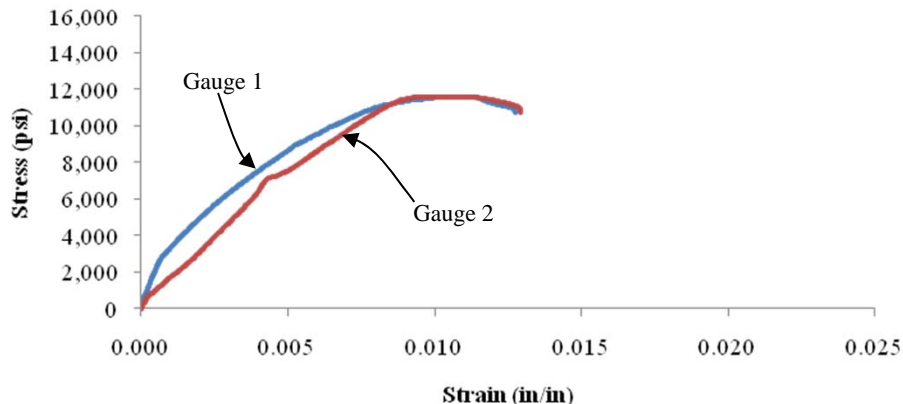
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|---------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00256 | 0.00053 | 1,714,610 |
| 2 | 0.00364 | 0.00145 | 1,585,537 |
| Average | | | 1,650,074 |

Stress-Strain Curve 140F_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by V-Notch Rail Shear Method (ASTM D7078/ D7078M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXY-05-140-FY09
 Test Date: 11/17/11
 Specimen Received: 8/31/11
 Properties Measured: S_{xy} , G_{xy}

Average Material Properties:

Maximum Load, P_{max} : 5,151 lbs
 Shear Strength, S_{xy} : 11,654 psi
 Shear Modulus, G_{xy} : 1,402,153 psi

Measured Specimen Dimensions:

Thickness, T: 0.8001 in
 Notch Length, N: 0.552 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 20% Max Load: 1,030 lbs
 50% Max Load: 2,576 lbs

PICTURE OF SPECIMEN PRE-TEST



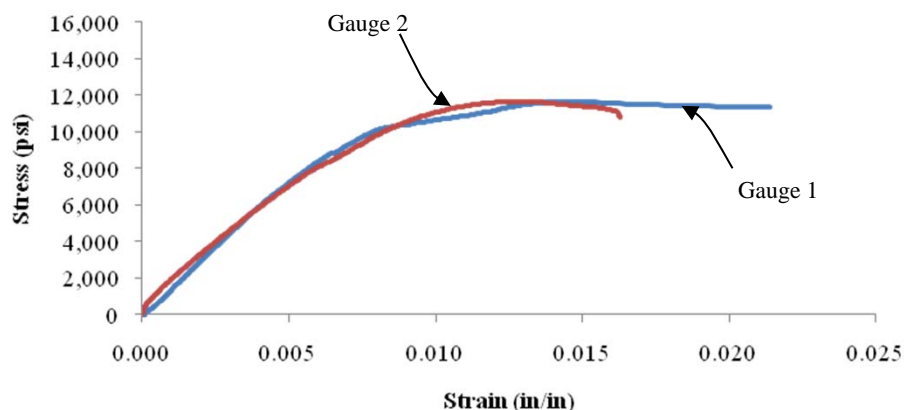
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max load (in/in) | Strain @ 20% Max load (in/in) | Shear Modulus, G_{xy} (psi) |
| 1 | 0.00391 | 0.00159 | 1,504,108 |
| 2 | 0.00393 | 0.00125 | 1,300,197 |
| Average | | | 1,402,153 |

Stress-Strain Curve 140F_05_(09-06)



Engineering Test notes:

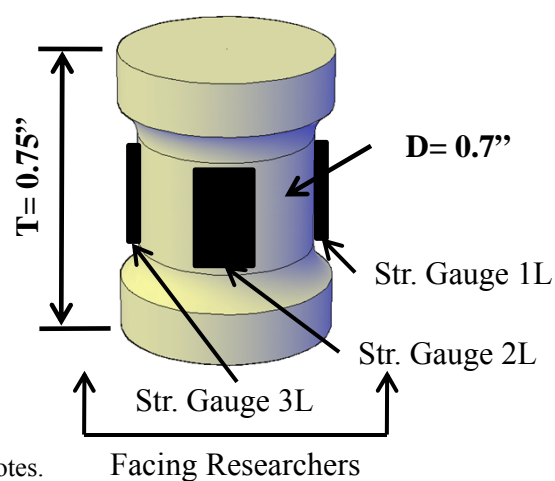
- *Specimen was fitted with two Vishay N2P-08-C032A-500/SP61 strain gauges (one on each side)
- *Shear Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test**TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)****TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS****Specimen ID Group:** MAT6-TZ-N40-FY09**Material:** Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**Nominal Temperature:** -40°F**Properties Measured:** σ_z , E_z **Average Material Properties (5 Specimens):****Ultimate Load, P_z :** 1,209 lbs**Tensile Strength, ST_z :** 3,206 psi**Tensile Modulus, E_z :** 1,085,445 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT6-TZ-1-N40-FY09 | 1,314 | 3,543 | 1,063,803 | Rupture |
| MAT6-TZ-2-N40-FY09 | 1,124 | 2,887 | 1,059,360 | Rupture |
| MAT6-TZ-3-N40-FY09 | 1,286 | 3,399 | 1,106,533 | Rupture |
| MAT6-TZ-4-N40-FY09 | 1,108 | 3,052 | 1,103,262 | Rupture |
| MAT6-TZ-5-N40-FY09 | 1,212 | 3,148 | 1,094,266 | Rupture |
| Average | 1,209 | 3,206 | 1,085,445 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-56 to I-60 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-1-N40-FY09**
 Test Date: 2/15/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

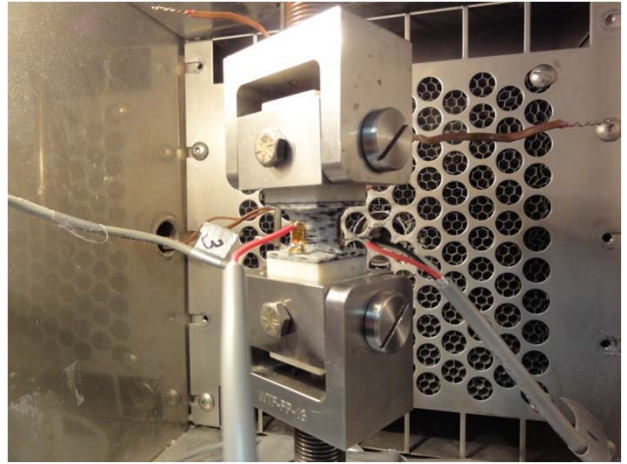
Average Material Properties:

Tensile Strength, ST_z : 3,543 psi
 Tensile Modulus, E_z : 1,063,803 psi

Measured Specimen Dimensions:

Diameter, D: 0.687 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,772 psi
 20% Max Stress: 709 psi

PICTURE OF SPECIMEN PRE-TEST



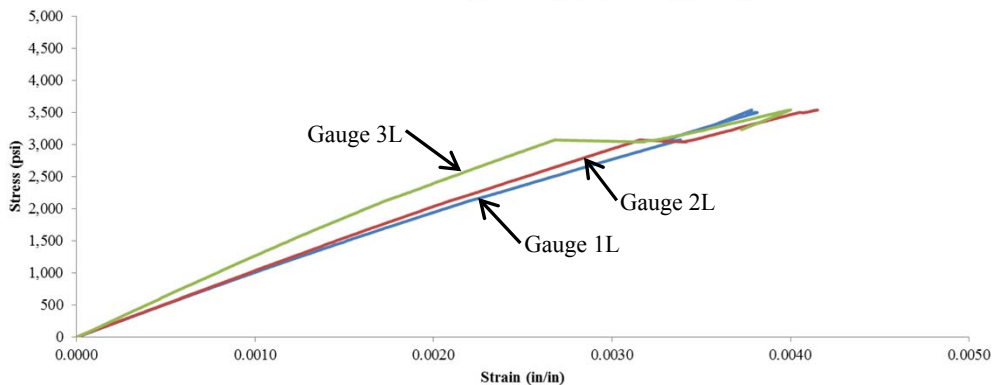
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001808 | 0.000694 | 954,039 |
| 2L | 0.001727 | 0.000682 | 1,017,248 |
| 3L | 0.001421 | 0.000550 | 1,220,123 |
| Average | | | 1,063,803 |

Stress-Strain Curve _-40°F_1_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-2-N40-FY09**
 Test Date: 2/28/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

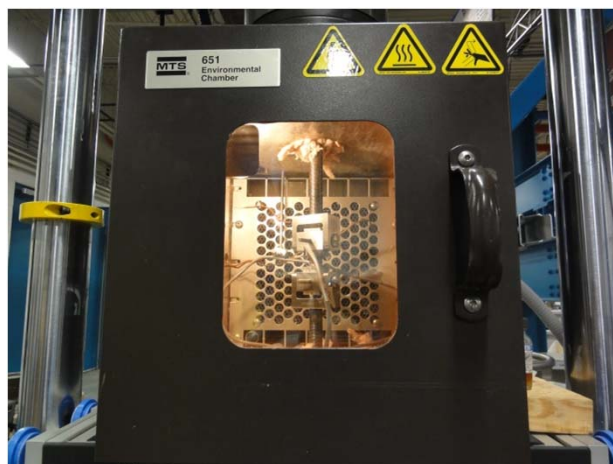
Average Material Properties:

Tensile Strength, ST_z : 2,887 psi
 Tensile Modulus, E_z : 1,059,360 psi

Measured Specimen Dimensions:

Diameter, D: 0.704 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,443 psi
 20% Max Stress: 577 psi

PICTURE OF SPECIMEN PRE-TEST



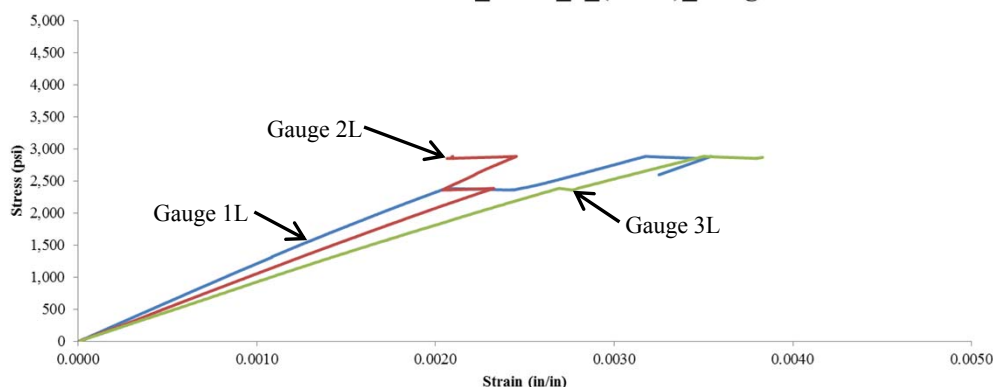
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001187 | 0.000469 | 1,206,447 |
| 2L | 0.001365 | 0.000545 | 1,055,395 |
| 3L | 0.001565 | 0.000620 | 916,238 |
| Average | | | 1,059,360 |

Stress-Strain Curve_-40°F_2_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-3-N40-FY09**
 Test Date: 2/28/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

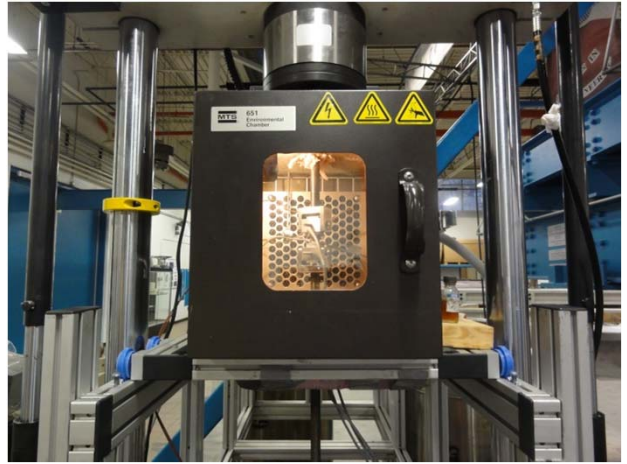
Average Material Properties:

Tensile Strength, ST_z : 3,399 psi
 Tensile Modulus, E_z : 1,106,533 psi

Measured Specimen Dimensions:

Diameter, D: 0.694 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,699 psi
 20% Max Stress: 680 psi

PICTURE OF SPECIMEN PRE-TEST



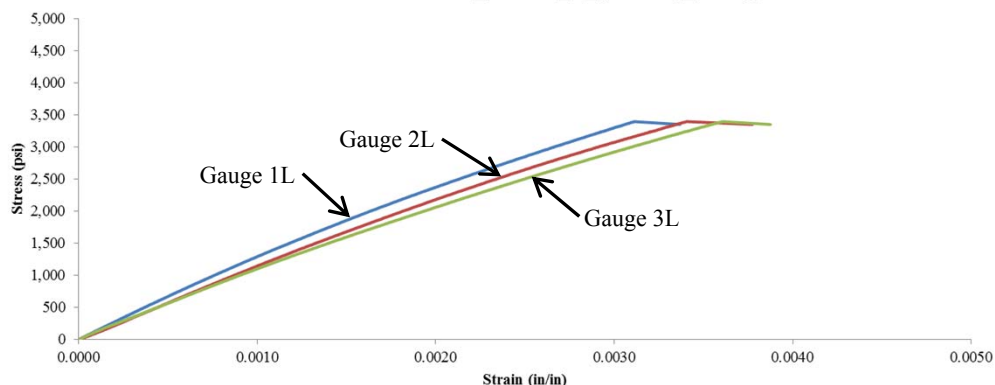
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001358 | 0.000508 | 1,200,378 |
| 2L | 0.001521 | 0.000595 | 1,101,602 |
| 3L | 0.001609 | 0.000607 | 1,017,619 |
| Average | | | 1,106,533 |

Stress-Strain Curve_ -40°F_3_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-4-N40-FY09**
 Test Date: 2/28/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

Average Material Properties:

Tensile Strength, ST_z : 3,052 psi
 Tensile Modulus, E_z : 1,103,262 psi

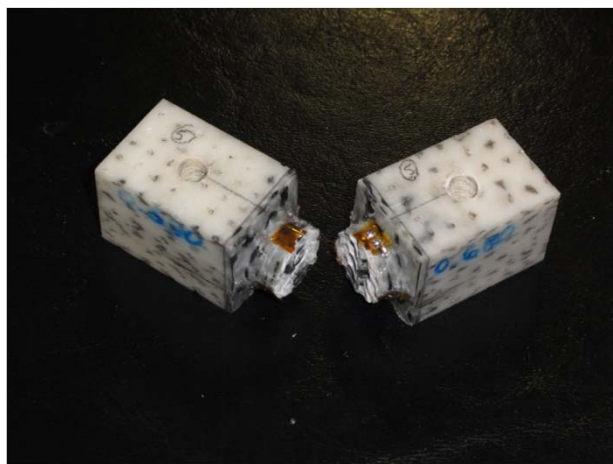
Measured Specimen Dimensions:

Diameter, D: 0.680 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,526 psi
 20% Max Stress: 610 psi

PICTURE OF SPECIMEN PRE-TEST



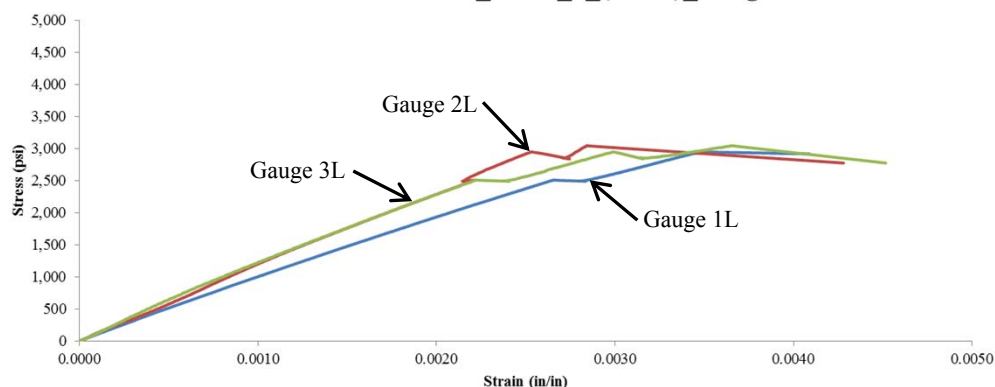
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001548 | 0.000593 | 958,669 |
| 2L | 0.001279 | 0.000526 | 1,214,958 |
| 3L | 0.001273 | 0.000467 | 1,136,161 |
| Average | | | 1,103,262 |

Stress-Strain Curve_-40°F_4_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-5-N40-FY09**
 Test Date: 2/28/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

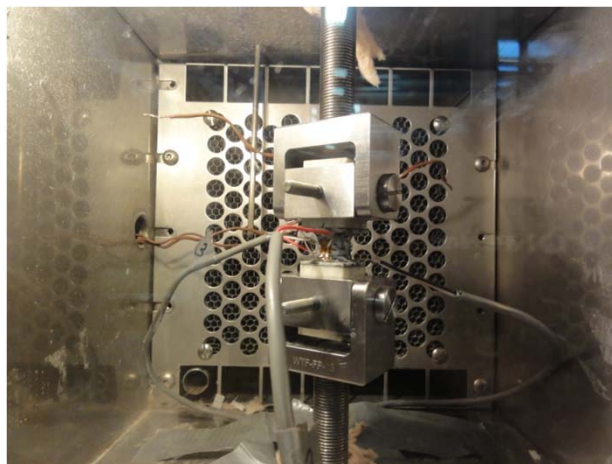
Average Material Properties:

Tensile Strength, ST_z : 3,148 psi
 Tensile Modulus, E_z : 1,094,266 psi

Measured Specimen Dimensions:

Diameter, D: 0.700 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,574 psi
 20% Max Stress: 630 psi

PICTURE OF SPECIMEN PRE-TEST



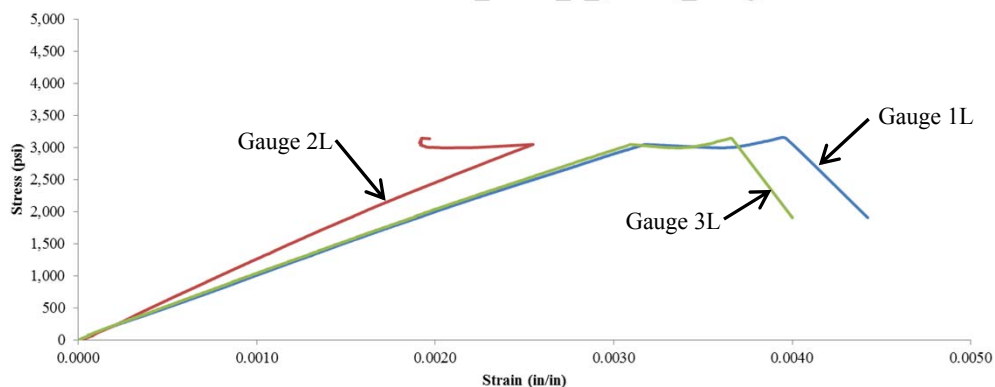
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001559 | 0.000622 | 1,007,600 |
| 2L | 0.001246 | 0.000502 | 1,268,796 |
| 3L | 0.001531 | 0.000592 | 1,006,401 |
| Average | | | 1,094,266 |

Stress-Strain Curve_-40°F_5_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-TZ-70-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 70°F

Properties Measured: σ_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 1,220 lbs

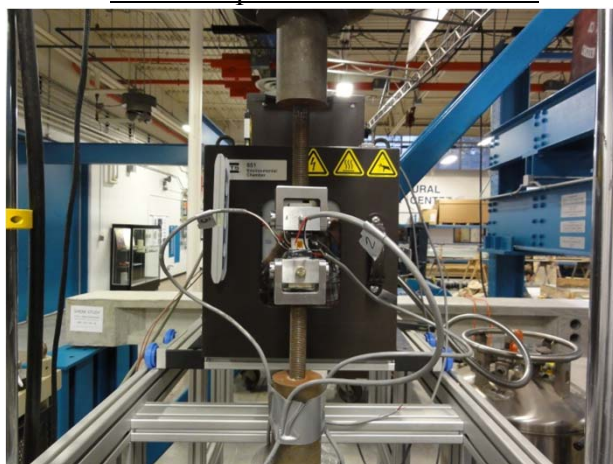
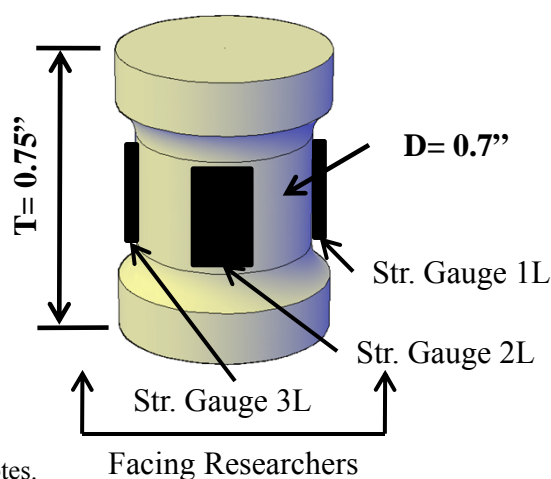
Tensile Strength, ST_z : 3,184 psi

Tensile Modulus, E_z : 975,756 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|-------------------|---------------------------|--------------------------------|------------------------------|--------------|
| MAT6-TZ-1-70-FY09 | 1,354 | 3,528 | 887,650 | Rupture |
| MAT6-TZ-2-70-FY09 | 1,234 | 3,225 | 1,022,021 | Rupture |
| MAT6-TZ-3-70-FY09 | 1,149 | 3,011 | 997,749 | Rupture |
| MAT6-TZ-4-70-FY09 | 1,099 | 2,863 | 996,925 | Rupture |
| MAT6-TZ-5-70-FY09 | 1,265 | 3,296 | 974,434 | Rupture |
| Average | 1,220 | 3,184 | 975,756 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-62 to I-66 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-1-70-FY09**
 Test Date: 12/09/2011
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

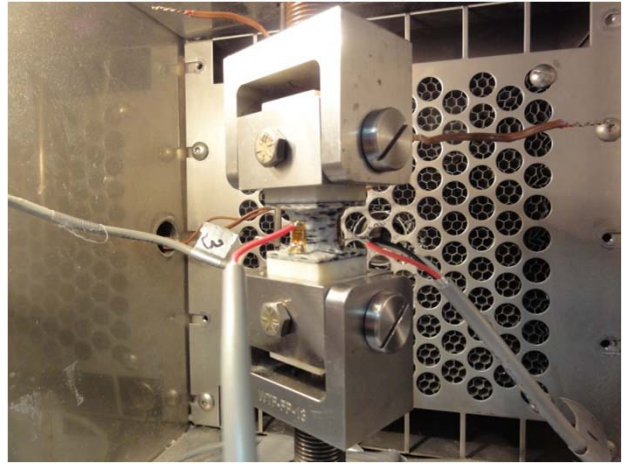
Average Material Properties:

Tensile Strength, ST_z : 3,528 psi
 Tensile Modulus, E_z : 887,650 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,764 psi
 20% Max Stress: 706 psi

PICTURE OF SPECIMEN PRE-TEST



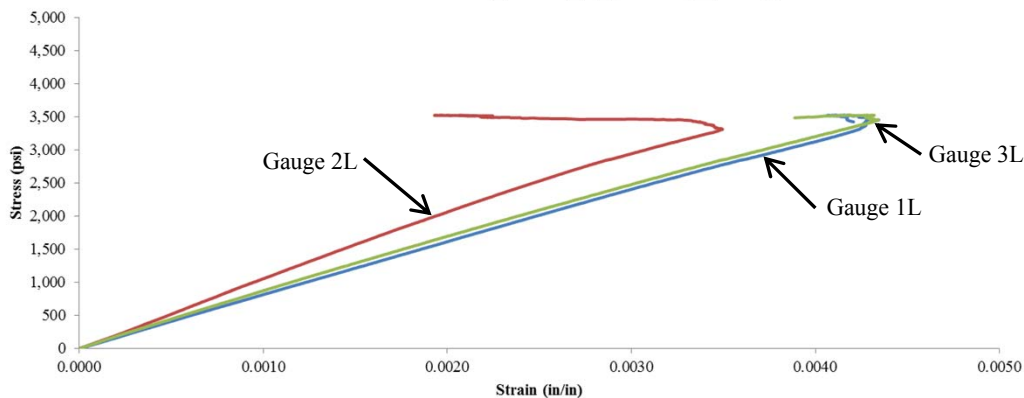
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002184 | 0.000863 | 801,111 |
| 2L | 0.001688 | 0.000668 | 1,037,743 |
| 3L | 0.002085 | 0.000800 | 824,096 |
| Average | | | 887,650 |

Stress-Strain Curve_70°F_1_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-2-70-FY09**
 Test Date: 12/09/2011
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

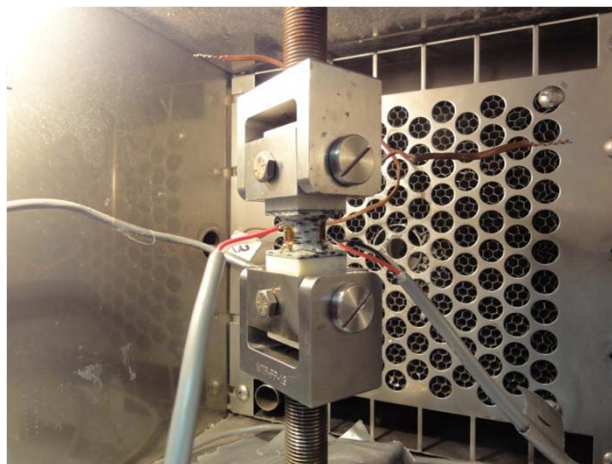
Average Material Properties:

Tensile Strength, ST_z : 3,225 psi
 Tensile Modulus, E_z : 1,022,021 psi

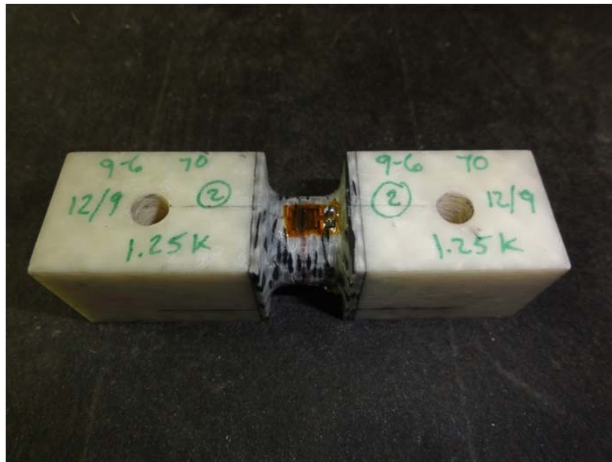
Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,612 psi
 20% Max Stress: 645 psi

PICTURE OF SPECIMEN PRE-TEST



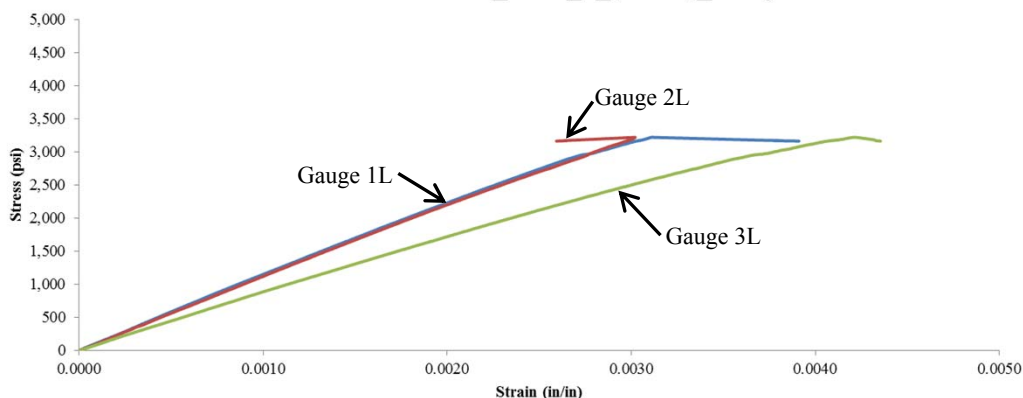
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001418 | 0.000549 | 1,113,227 |
| 2L | 0.001445 | 0.000572 | 1,107,818 |
| 3L | 0.001867 | 0.000723 | 845,019 |
| Average | | | 1,022,021 |

Stress-Strain Curve_70°F_2_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-3-70-FY09**
 Test Date: 12/09/2011
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

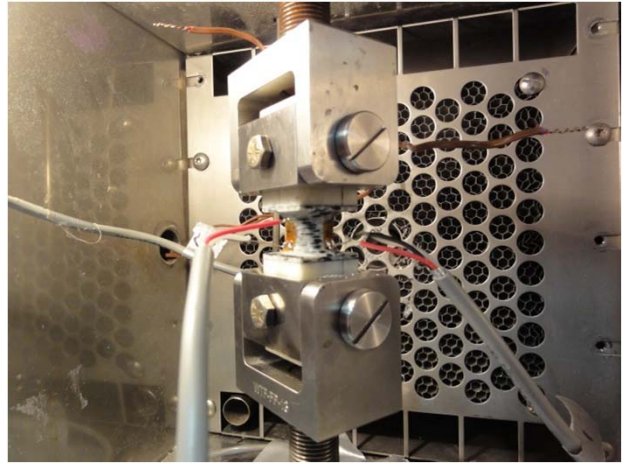
Average Material Properties:

Tensile Strength, ST_z : 3,011 psi
 Tensile Modulus, E_z : 997,749 psi

Measured Specimen Dimensions:

Diameter, D: 0.697 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,505 psi
 20% Max Stress: 602 psi

PICTURE OF SPECIMEN PRE-TEST



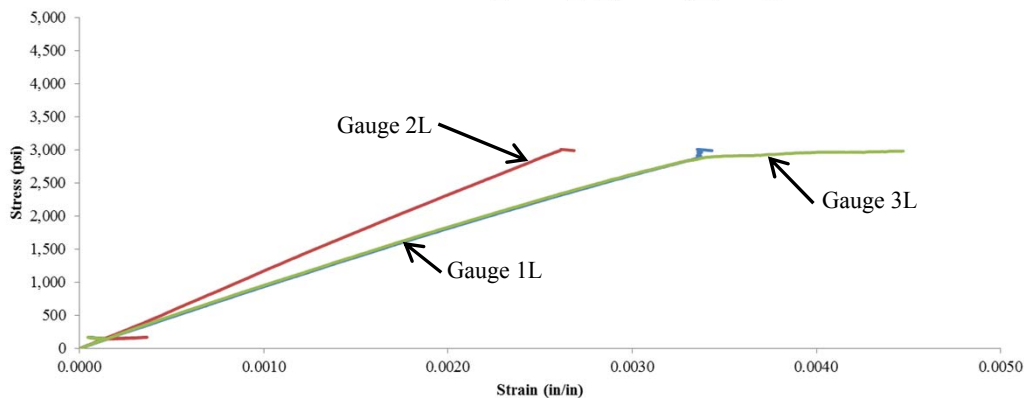
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001640 | 0.000635 | 899,522 |
| 2L | 0.001280 | 0.000524 | 1,194,403 |
| 3L | 0.001619 | 0.000615 | 899,321 |
| Average | | | 997,749 |

Stress-Strain Curve_70°F_3_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-4-70-FY09**
 Test Date: 12/09/2011
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

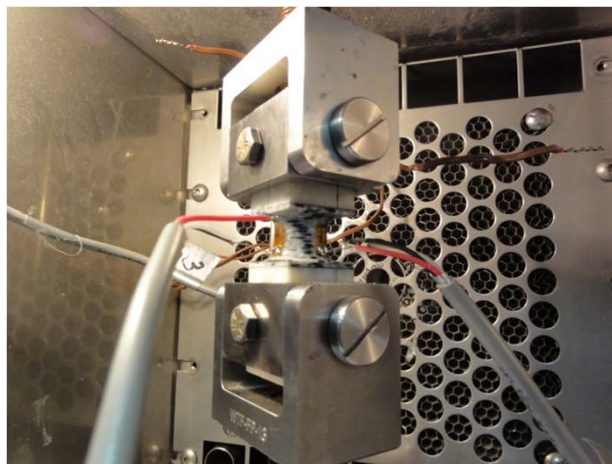
Average Material Properties:

Tensile Strength, ST_z : 2,863 psi
 Tensile Modulus, E_z : 996,925 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,431 psi
 20% Max Stress: 573 psi

PICTURE OF SPECIMEN PRE-TEST



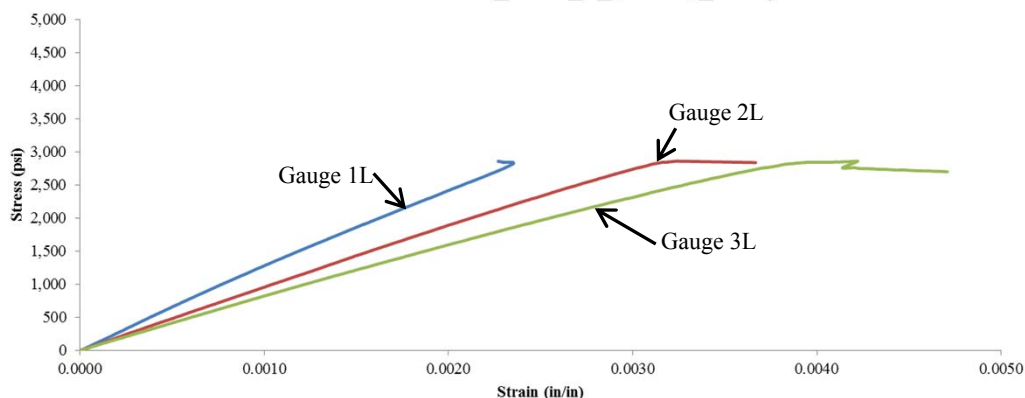
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001124 | 0.000435 | 1,246,837 |
| 2L | 0.001495 | 0.000593 | 952,737 |
| 3L | 0.001778 | 0.000692 | 791,203 |
| Average | | | 996,925 |

Stress-Strain Curve_70°F_4_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-5-70-FY09**
 Test Date: 12/09/2011
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

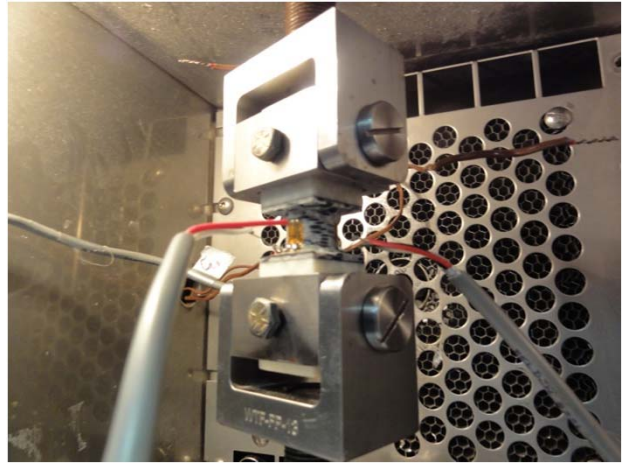
Average Material Properties:

Tensile Strength, ST_z : 3,296 psi
 Tensile Modulus, E_z : 974,434 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 1,648 psi
 20% Max Stress: 659 psi

PICTURE OF SPECIMEN PRE-TEST



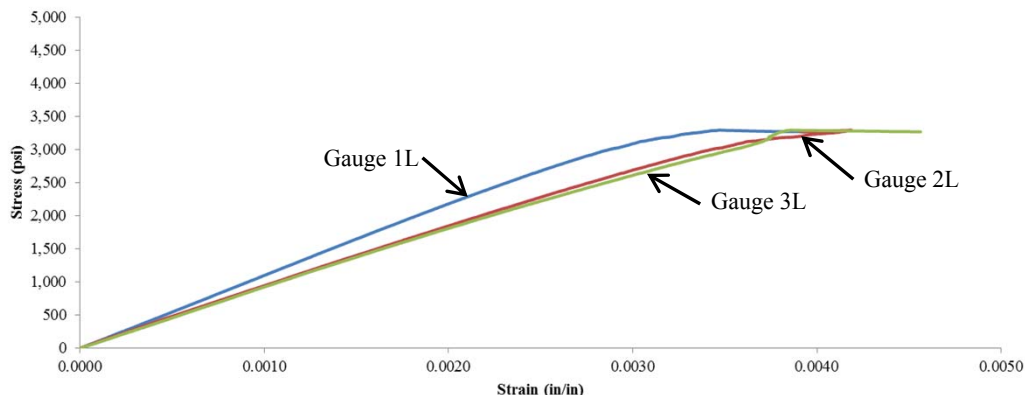
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001498 | 0.000603 | 1,104,735 |
| 2L | 0.001772 | 0.000692 | 914,980 |
| 3L | 0.001812 | 0.000717 | 903,587 |
| Average | | | 974,434 |

Stress-Strain Curve_70°F_5_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-Of-Plane Tensile Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material (ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS – AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-TZ-140-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 140°F

Properties Measured: σ_z , E_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 616 lbs

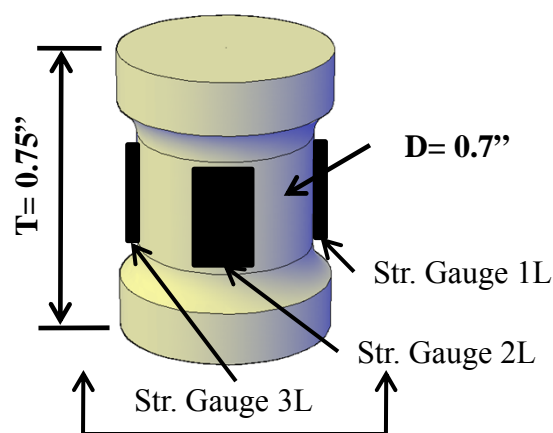
Tensile Strength, ST_z : 1,601 psi

Tensile Modulus, E_z : 370,642 psi

| TEST | Maximum Load, P_z (lbs) | Tensile Strength, ST_z (psi) | Tensile Modulus, E_z (psi) | Failure Mode |
|--------------------|------------------------------|-----------------------------------|---------------------------------|--------------|
| MAT6-TZ-1-140-FY09 | 648 | 1,678 | 381,898 | Rupture |
| MAT6-TZ-2-140-FY09 | 660 | 1,696 | 476,090 | Rupture |
| MAT6-TZ-3-140-FY09 | 569 | 1,483 | 318,939 | Rupture |
| MAT6-TZ-4-140-FY09 | 574 | 1,505 | 360,345 | Rupture |
| MAT6-TZ-5-140-FY09 | 629 | 1,643 | 315,939 | Rupture |
| Average | 616 | 1,601 | 370,642 | |

Test Description:

The Flat Wise Tensile Test, performed within the guidelines of ASTM D7291, measures the through-thickness “flatwise” tensile strength and tensile modulus of fiber reinforced polymer matrix composite materials. The fiber laminates are orientated along two axes known as the x and y-axes. There are no fibers directly oriented in the direction of the third axis known as the z-axis. A tensile force is applied at a rate of 0.005 in/min along the z-axis using adhesively bonded end-tabs. The specimen consists of a cylinder with a reduced gauge section. Three longitudinal strain gauges are adhered 120 degrees apart to the specimen (1L, 2L, and 3L) as shown below. A universal joint is attached above and below the specimen to allow uniaxial tension. This test is performed on the Instron 8502A.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-68 to I-72 for individual specimen test summary sheets and notes.
- 2) Rupture indicates ASTM accepted failure at greater than 1 ply from the epoxied bondline at the base of the specimen.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-1-140-FY09**
 Test Date: 2/14/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

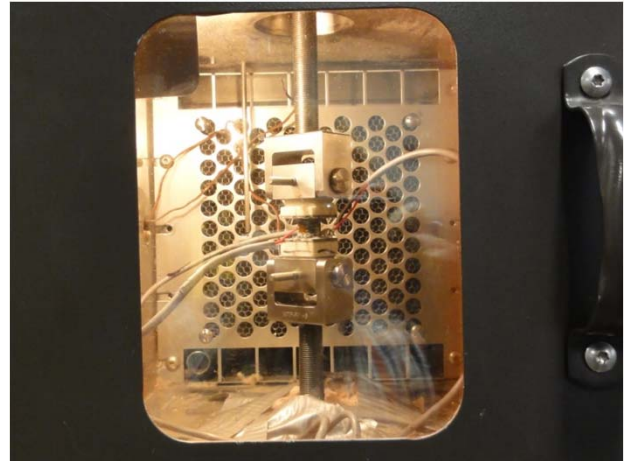
Average Material Properties:

Tensile Strength, ST_z : 1,678 psi
 Tensile Modulus, E_z : 381,898 psi

Measured Specimen Dimensions:

Diameter, D: 0.701 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 839 psi
 20% Max Stress: 336 psi

PICTURE OF SPECIMEN PRE-TEST



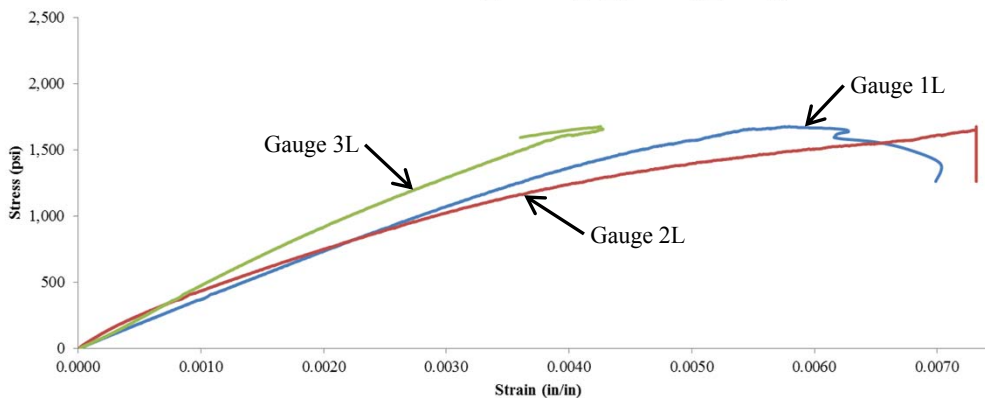
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.002287 | 0.000896 | 361,998 |
| 2L | 0.002298 | 0.000720 | 319,016 |
| 3L | 0.001799 | 0.000716 | 464,680 |
| Average | | | 381,898 |

Stress-Strain Curve_140°F_1_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-2-140-FY09**
 Test Date: 2/16/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

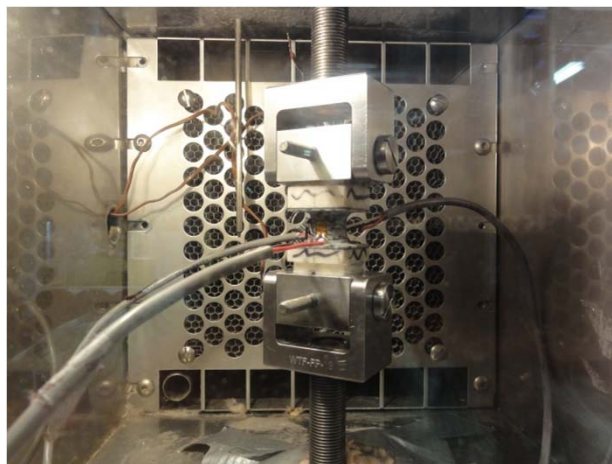
Average Material Properties:

Tensile Strength, ST_z : 1,696 psi
 Tensile Modulus, E_z : 476,090 psi

Measured Specimen Dimensions:

Diameter, D: 0.704 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 848 psi
 20% Max Stress: 339 psi

PICTURE OF SPECIMEN PRE-TEST



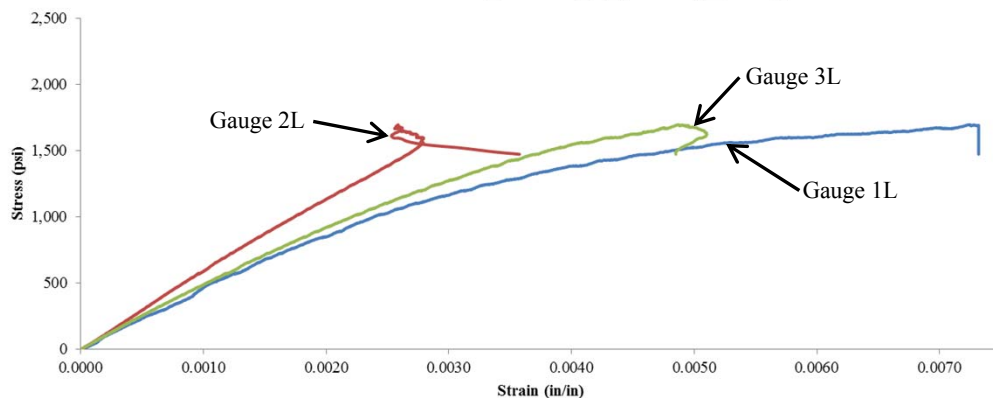
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001994 | 0.000764 | 413,568 |
| 2L | 0.001455 | 0.000570 | 574,614 |
| 3L | 0.001830 | 0.000674 | 440,090 |
| Average | | | 476,090 |

Stress-Strain Curve_140°F_2_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-3-140-FY09**
 Test Date: 4/25/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

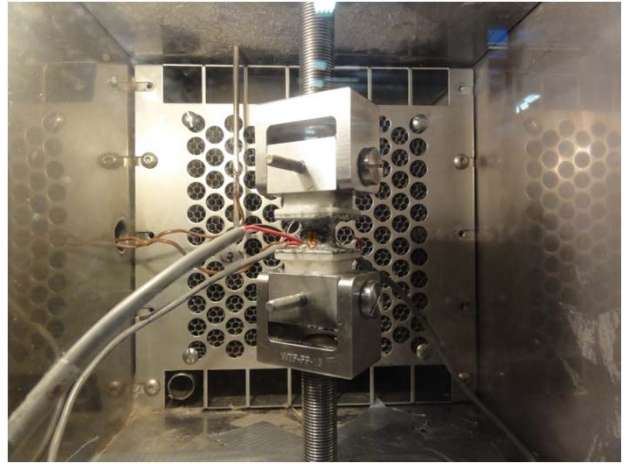
Average Material Properties:

Tensile Strength, ST_z : 1,483 psi
 Tensile Modulus, E_z : 318,939 psi

Measured Specimen Dimensions:

Diameter, D: 0.699 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 741 psi
 20% Max Stress: 297 psi

PICTURE OF SPECIMEN PRE-TEST



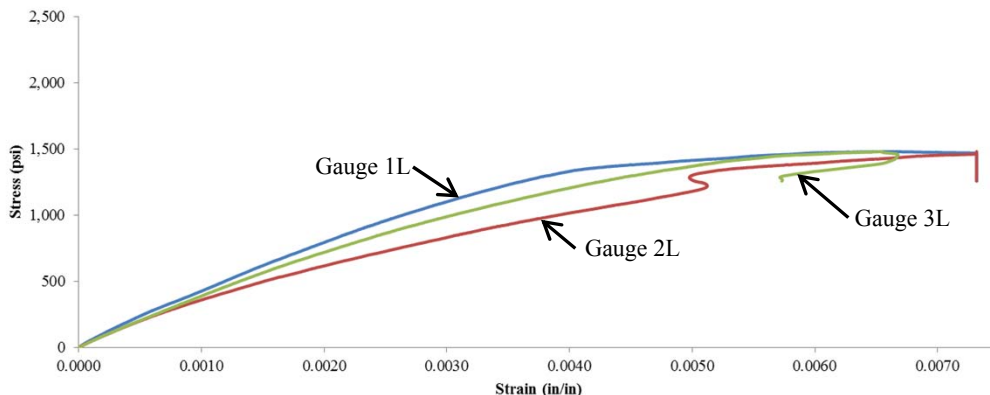
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001844 | 0.000644 | 370,785 |
| 2L | 0.002562 | 0.000787 | 250,596 |
| 3L | 0.002070 | 0.000744 | 335,436 |
| Average | | | 318,939 |

Stress-Strain Curve_140°F_3_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-4-140-FY09**
 Test Date: 4/25/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

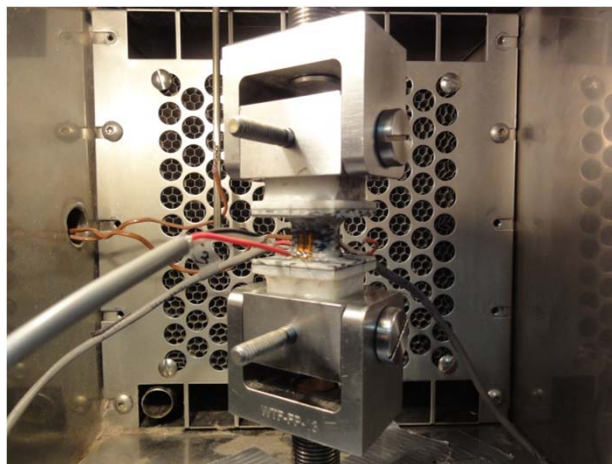
Average Material Properties:

Tensile Strength, ST_z : 1,505 psi
 Tensile Modulus, E_z : 360,345 psi

Measured Specimen Dimensions:

Diameter, D: 0.697 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 752 psi
 20% Max Stress: 301 psi

PICTURE OF SPECIMEN PRE-TEST



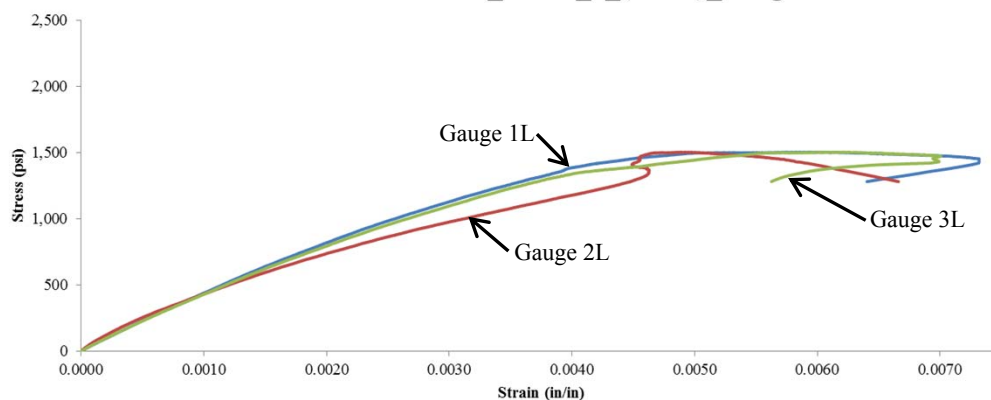
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.001810 | 0.000657 | 391,812 |
| 2L | 0.002055 | 0.000615 | 313,437 |
| 3L | 0.001871 | 0.000670 | 375,787 |
| Average | | | 360,345 |

Stress-Strain Curve_140°F_4_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-TZ-5-140-FY09**
 Test Date: 4/25/2012
 Specimen Received: 7/07/2011
 Properties Measured: σ_z , E_z

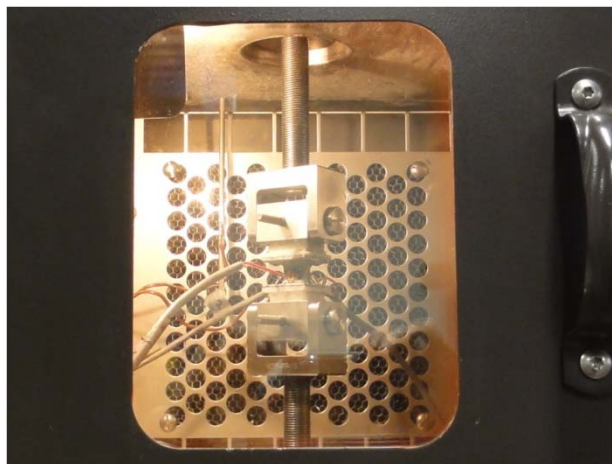
Average Material Properties:

Tensile Strength, ST_z : 1,643 psi
 Tensile Modulus, E_z : 315,939 psi

Measured Specimen Dimensions:

Diameter, D: 0.698 in
 Laboratory Temperature: 68°F
 Failure Mode: Rupture
 50% Max Stress: 822 psi
 20% Max Stress: 329 psi

PICTURE OF SPECIMEN PRE-TEST



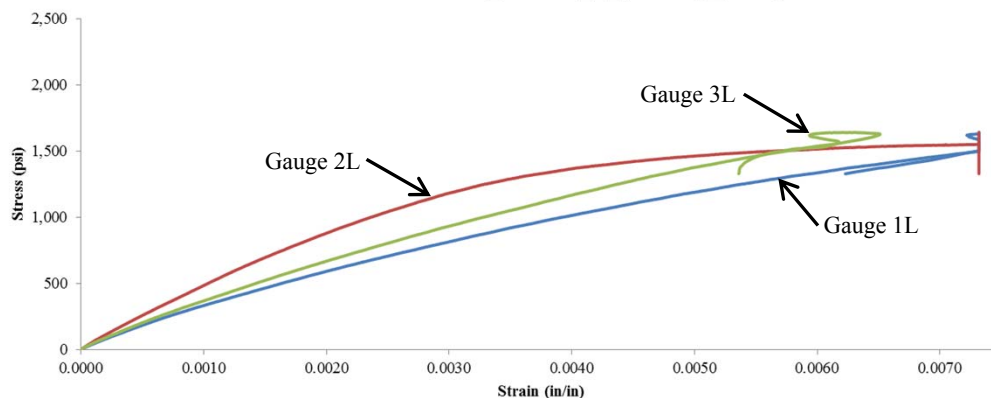
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-------------------------------------|
| Gauge | Strain @ 50% Max Stress ϵ , (in/in) | Strain @ 20% Max Stress ϵ , (in/in) | Tensile Modulus E_z , (psi) |
| 1L | 0.003029 | 0.000981 | 240,723 |
| 2L | 0.001835 | 0.000650 | 416,183 |
| 3L | 0.002564 | 0.000869 | 290,911 |
| Average | | | 315,939 |

Stress-Strain Curve_140°F_5_(09-06)_Long



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

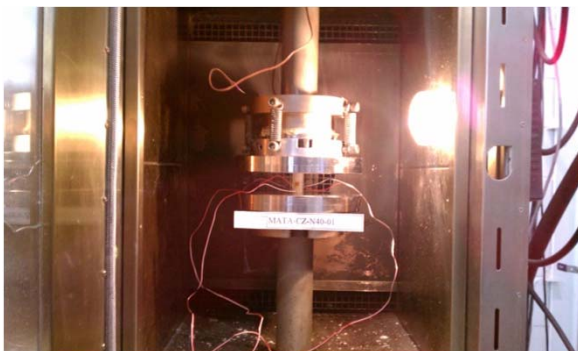
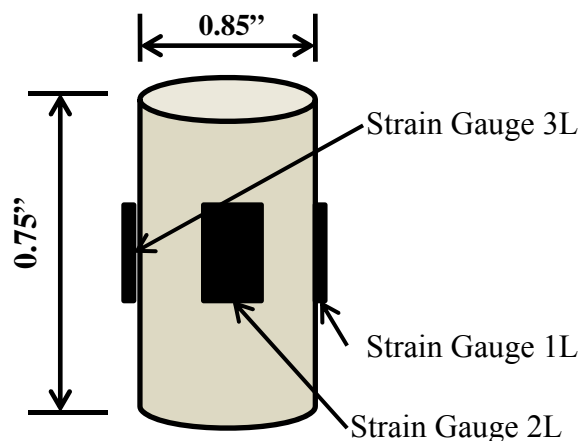
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-CZ-N40-FY09
 Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric
 Nominal Temperature: -40°F
 Properties Measured: SC_z , E_z , ϵ_z
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : 26,288 lbs
 Compressive Strength, SC_z : 46,546 psi
 Compressive Modulus, E_z : 1,081,349 psi
 Ultimate Strain, ϵ_z : 0.044 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT6-CZ-01-N40-FY09 | 26,012 | 46,007 | 1,072,542 | 0.043 | Rupture |
| MAT6-CZ-02-N40-FY09 | 26,843 | 47,737 | 1,014,636 | 0.047 | Rupture |
| MAT6-CZ-03-N40-FY09 | 25,919 | 45,841 | 1,075,941 | 0.045 | Rupture |
| MAT6-CZ-04-N40-FY09 | 25,655 | 45,495 | 1,046,817 | 0.045 | Rupture |
| MAT6-CZ-05-N40-FY09 | 27,013 | 47,651 | 1,196,811 | 0.041 | Rupture |
| Average | 26,288 | 46,546 | 1,081,349 | 0.044 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for the Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber laminate direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

-40°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-74 to I-78 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-01-N40-FY09**
 Test Date: 9/13/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 26,012 lbs
 Maximum Stress, SC_z : 46,007 psi
 Compressive Modulus, E_z : 1,072,542 psi
 Ultimate Strain, ϵ_z : 0.043 in/in

Measured Specimen Dimensions:

Length, L: 0.8106 in
 Diameter, D: 0.8485 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,202 psi
 50% Max Load: 13,006 psi

PICTURE OF SPECIMEN PRE-TEST



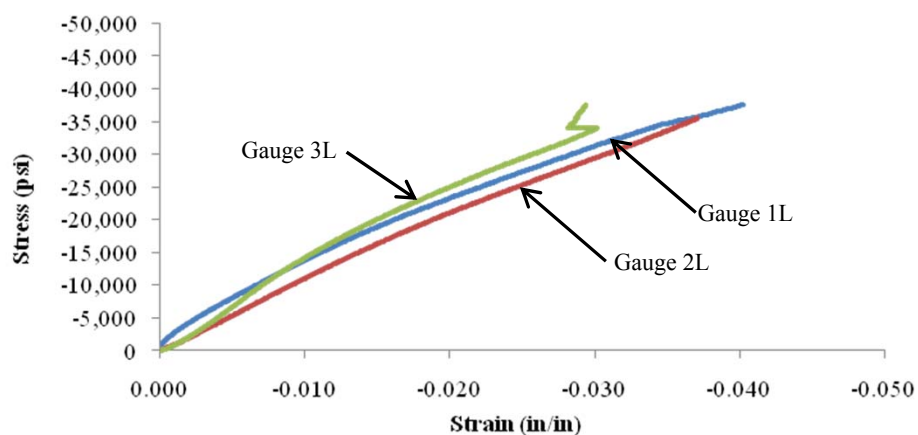
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01962 | -0.00594 | 1,008,703 |
| 2L | -0.02221 | -0.00833 | 994,547 |
| 3L | -0.01788 | -0.00651 | 1,214,376 |
| Average | | | 1,072,542 |

Stress-Strain Curve N40_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-02-N40-FY-09**
 Test Date: 9/13/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 26,843 lbs
 Maximum Stress, SC_z : 47,737 psi
 Compressive Modulus, E_z : 1,014,636 psi
 Ultimate Strain, ϵ_z : 0.047 in/in

Measured Specimen Dimensions:

Length, L: 0.7934 in
 Diameter, D: 0.8461 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,369 psi
 50% Max Load: 13,421 psi

PICTURE OF SPECIMEN PRE-TEST



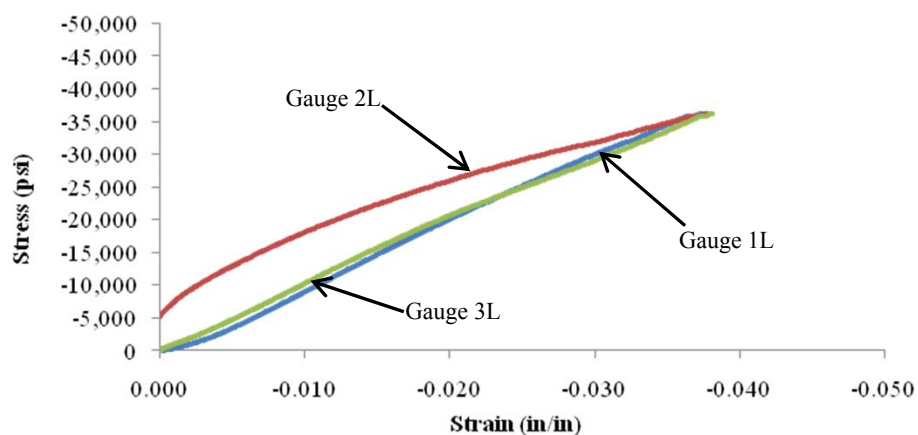
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02371 | -0.01047 | 1,081,096 |
| 2L | -0.01703 | -0.00224 | 968,610 |
| 3L | -0.02373 | -0.00933 | 994,201 |
| Average | | | 1,014,636 |

Stress-Strain Curve N40_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-03-N40-FY-09**
 Test Date: 9/13/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 25,919 lbs
 Maximum Stress, SC_z : 45,841 psi
 Compressive Modulus, E_z : 1,075,941 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

Measured Specimen Dimensions:

Length, L: 0.8233 in
 Diameter, D: 0.8485 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,184 psi
 50% Max Load: 12,959 psi

PICTURE OF SPECIMEN PRE-TEST



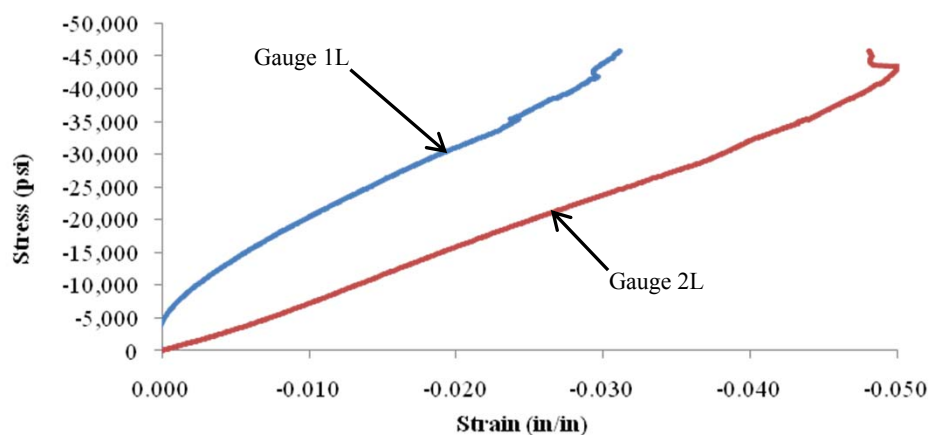
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01220 | -0.00185 | 1,328,422 |
| 2L | -0.02889 | -0.01219 | 823,460 |
| 3L | Lost Gauge | Lost Gauge | - |
| Average | | | 1,075,941 |

Stress-Strain Curve N40_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-04-N40-FY-09**
 Test Date: 9/13/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 25,655 lbs
 Maximum Stress, SC_z : 45,495 psi
 Compressive Modulus, E_z : 1,046,817 psi
 Ultimate Strain, ϵ_z : 0.045 in/in

Measured Specimen Dimensions:

Length, L: 0.8095 in
 Diameter, D: 0.8473 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,131 psi
 50% Max Load: 12,827 psi

PICTURE OF SPECIMEN PRE-TEST



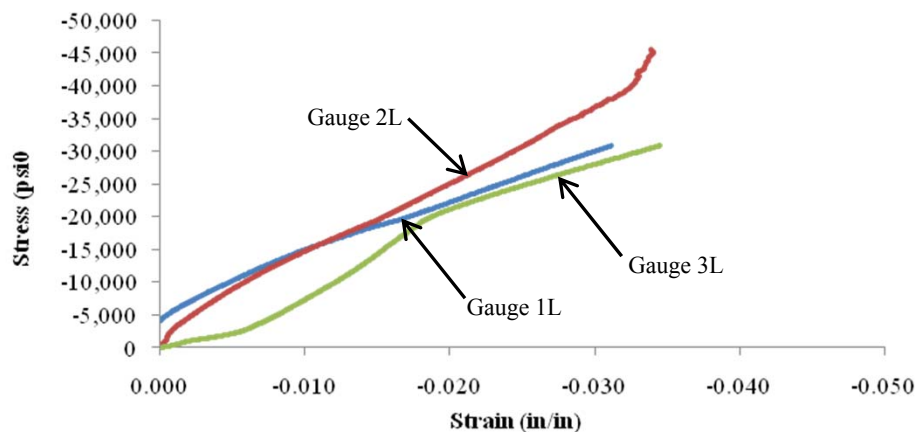
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02071 | -0.00391 | 812,372 |
| 2L | -0.01794 | -0.00511 | 1,063,595 |
| 3L | -0.02218 | -0.01139 | 1,264,482 |
| Average | | | 1,046,817 |

Stress-Strain Curve N40_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-05-N40-FY-09**
 Test Date: 9/13/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 27,013 lbs
 Maximum Stress, SC_z : 47,651 psi
 Compressive Modulus, E_z : 1,196,811 psi
 Ultimate Strain, ϵ_z : 0.041 in/in

Measured Specimen Dimensions:

Length, L: 0.8107 in
 Diameter, D: 0.8496 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 5,403 psi
 50% Max Load: 13,507 psi

PICTURE OF SPECIMEN PRE-TEST



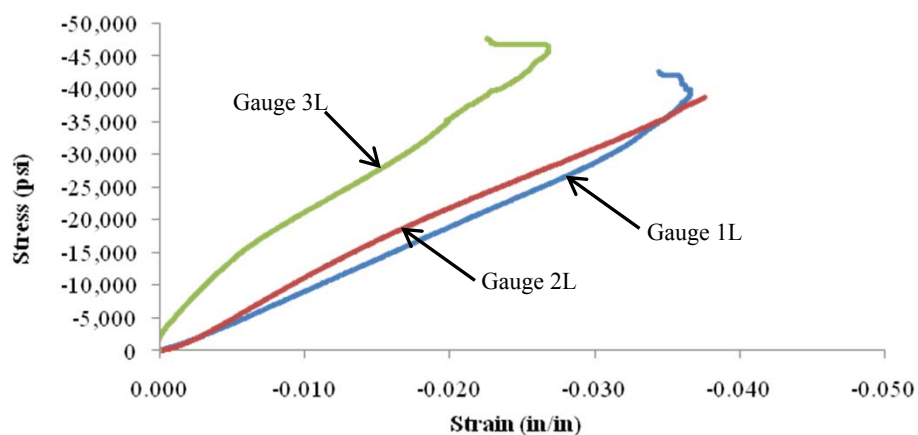
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.02507 | -0.01045 | 978,202 |
| 2L | -0.02214 | -0.00864 | 1,058,996 |
| 3L | -0.01208 | -0.00288 | 1,553,235 |
| Average | | | 1,196,811 |

Stress-Strain Curve N40_05_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

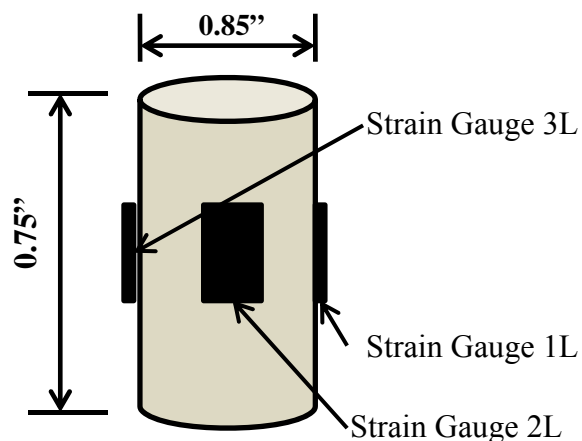
TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-CZ-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**
 Nominal Temperature: **70°F**
 Properties Measured: **SC_z , E_z , ϵ_z**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_z : **19,830** **lbs**
 Compressive Strength, SC_z : **35,111** **psi**
 Compressive Modulus, E_z : **935,208** **psi**
 Ultimate Strain, ϵ_z : **0.038** **in/in**

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|--------------------|------------------------------|---------------------------------------|-------------------------------------|--|--------------|
| MAT6-CZ-01-70-FY09 | 18,262 | 32,310 | 920,156 | 0.036 | Rupture |
| MAT6-CZ-02-70-FY09 | 20,050 | 35,498 | 849,975 | 0.042 | Rupture |
| MAT6-CZ-03-70-FY09 | 20,732 | 36,602 | 930,557 | 0.040 | Rupture |
| MAT6-CZ-04-70-FY09 | 20,242 | 35,827 | 1,012,851 | 0.036 | Rupture |
| MAT6-CZ-05-70-FY09 | 19,862 | 35,317 | 962,500 | 0.038 | Rupture |
| Average | 19,830 | 35,111 | 935,208 | 0.038 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-80 to I-84 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-01-70-FY09**
 Test Date: 9/8/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 18,262 lbs
 Maximum Stress, SC_z : 32,310 psi
 Compressive Modulus, E_z : 920,156 psi
 Ultimate Strain, ϵ_z : 0.036 in/in

Measured Specimen Dimensions:

Length, L: 0.8118 in
 Diameter, D: 0.8483 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 3,652 psi
 50% Max Load: 9,131 psi

PICTURE OF SPECIMEN PRE-TEST



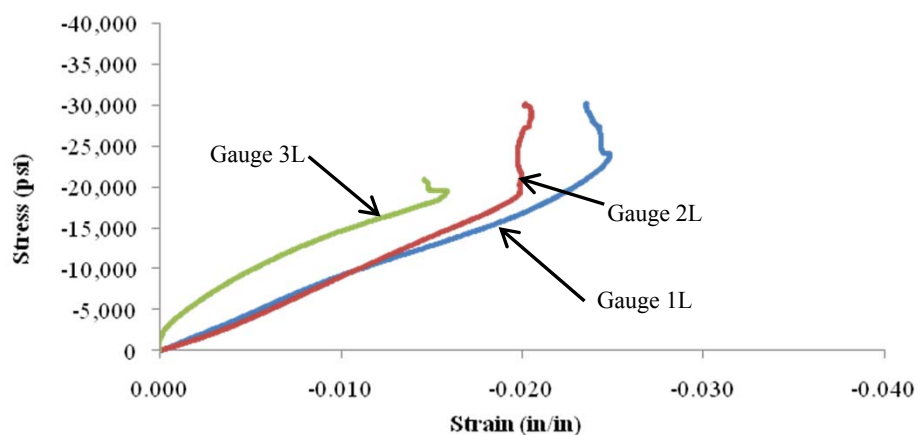
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01931 | -0.00691 | 781,815 |
| 2L | -0.01738 | -0.00749 | 980,307 |
| 3L | -0.01214 | -0.00243 | 998,347 |
| Average | | | 920,156 |

Stress-Strain Curve 70F_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-02-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 20,050 lbs
 Maximum Stress, SC_z : 35,498 psi
 Compressive Modulus, E_z : 849,975 psi
 Ultimate Strain, ϵ_z : 0.042 in/in

Measured Specimen Dimensions:

Length, L: 0.8039 in
 Diameter, D: 0.8480 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 4,010 psi
 50% Max Load: 10,025 psi

PICTURE OF SPECIMEN PRE-TEST



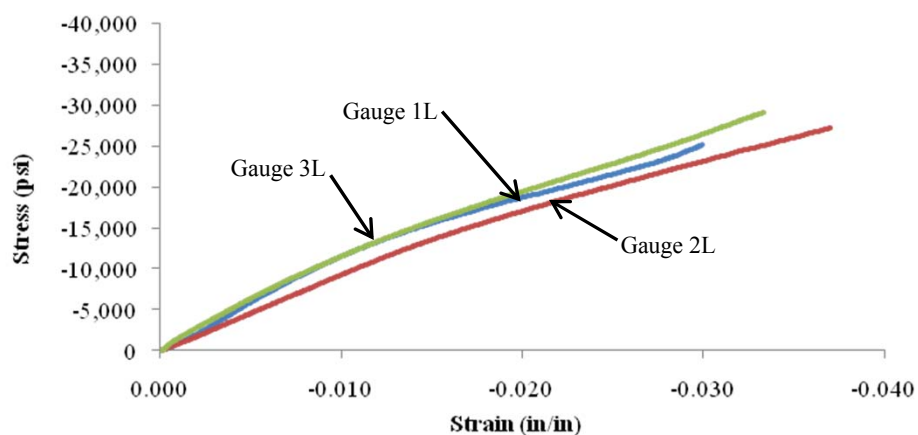
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---|
| Gauge | Strain @ 50% Max Load ϵ_z , (in/in) | Strain @ 20% Max Load ϵ_z , (in/in) | Compressive Modulus E_z , (psi) |
| 1L | -0.01837 | -0.00598 | 859,576 |
| 2L | -0.02108 | -0.00771 | 796,618 |
| 3L | -0.01758 | -0.00566 | 893,732 |
| Average | | | 849,975 |

Stress-Strain Curve 70F_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-03-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 20,732 lbs
 Maximum Stress, SC_z : 36,602 psi
 Compressive Modulus, E_z : 930,557 psi
 Ultimate Strain, ϵ_z : 0.040 in/in

Measured Specimen Dimensions:

Length, L: 0.7991 in
 Diameter, D: 0.8482 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 4,146 psi
 50% Max Load: 10,366 psi

PICTURE OF SPECIMEN PRE-TEST



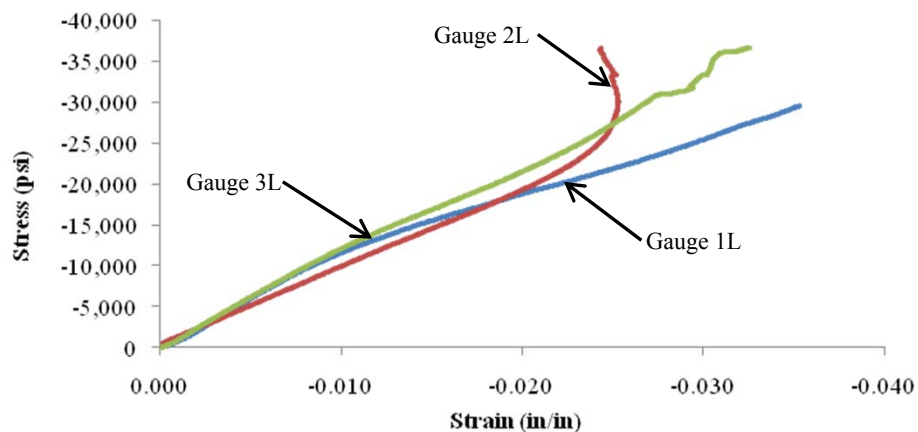
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|-----------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Elastic Modulus E_z (psi) |
| 1L | -0.01925 | -0.00605 | 831,730 |
| 2L | -0.01904 | -0.00725 | 931,724 |
| 3L | -0.01660 | -0.00592 | 1,028,217 |
| Average | | | 930,557 |

Stress-Strain Curve 70F_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-04-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 20,242 lbs
 Maximum Stress, SC_z : 35,827 psi
 Compressive Modulus, E_z : 1,012,851 psi
 Ultimate Strain, ϵ_z : 0.036 in/in

Measured Specimen Dimensions:

Length, L: 0.8018 in
 Diameter, D: 0.8482 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 4,048 psi
 50% Max Load: 10,121 psi

PICTURE OF SPECIMEN PRE-TEST



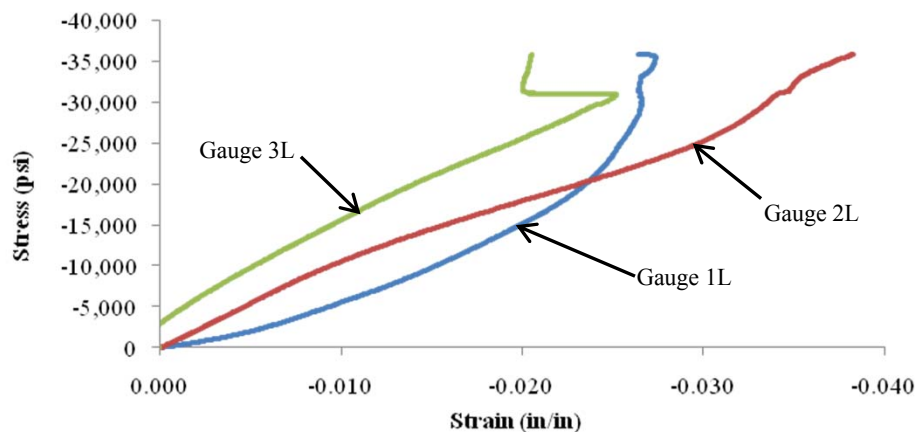
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02221 | -0.01208 | 1,060,917 |
| 2L | -0.01998 | -0.00656 | 800,452 |
| 3L | -0.01205 | -0.00292 | 1,177,182 |
| Average | | | 1,012,851 |

Stress-Strain Curve 70F_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-05-70-FY09**
 Test Date: 9/12/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 19,862 lbs
 Maximum Stress, SC_z : 35,317 psi
 Compressive Modulus, E_z : 962,500 psi
 Ultimate Strain, ϵ_z : 0.038 in/in

Measured Specimen Dimensions:

Length, L: 0.8115 in
 Diameter, D: 0.8462 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 3,972 psi
 50% Max Load: 9,931 psi

PICTURE OF SPECIMEN PRE-TEST



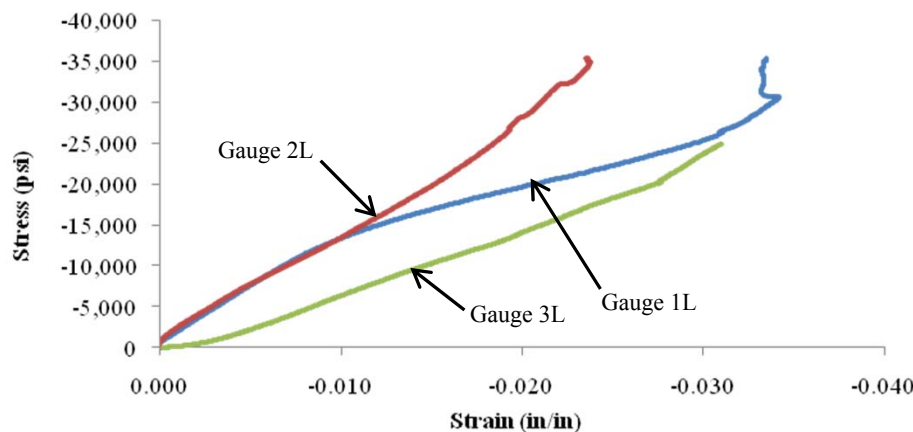
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01625 | -0.00458 | 908,101 |
| 2L | -0.01334 | -0.00438 | 1,182,904 |
| 3L | -0.02414 | -0.01083 | 796,494 |
| Average | | | 962,500 |

Stress-Strain Curve 70F_05_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET – Out-of-Plane Compression Test

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY/RESULTS - AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-CZ-140-FY09

Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric

Nominal Temperature: 140°F

Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties (5 Specimens):

Ultimate Load, P_z : 15,064 lbs

Compressive Strength, SC_z : 27,001 psi

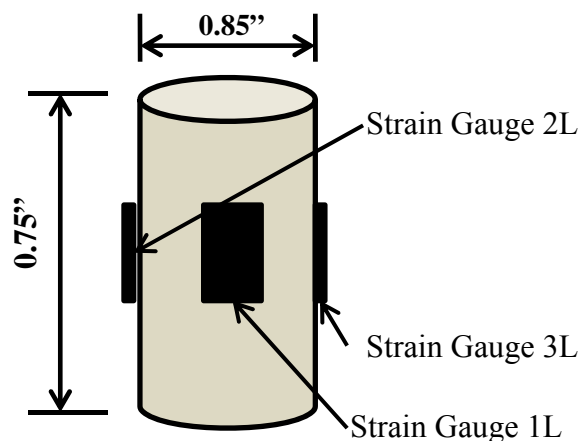
Compressive Modulus, E_z : 799,320 psi

Ultimate Strain, ϵ_z : 0.035 in/in

| Specimen | Maximum Load, P_z (lbs) | Compressive Strength, SC_z (psi) | Compressive Modulus, E_z (psi) | Ultimate Strain, ϵ_z (in/in) | Failure Mode |
|---------------------|---------------------------|------------------------------------|----------------------------------|---------------------------------------|--------------|
| MAT6-CZ-01-140-FY09 | 14,967 | 26,703 | 718,533 | 0.039 | Rupture |
| MAT6-CZ-02-140-FY09 | 15,523 | 27,415 | 806,729 | 0.035 | Rupture |
| MAT6-CZ-03-140-FY09 | 14,972 | 27,619 | 836,495 | 0.033 | Rupture |
| MAT6-CZ-04-140-FY09 | 15,110 | 26,968 | 819,277 | 0.033 | Rupture |
| MAT6-CZ-05-140-FY09 | 14,747 | 26,301 | 815,566 | 0.034 | Rupture |
| Average | 15,064 | 27,001 | 799,320 | 0.035 | |

Test Description:

The Out-of-Plane Compression Test measures the through-thickness “flatwise” compressive strength and elastic modulus of fiber reinforced polymer matrix composite materials. The general testing procedure is similar to that performed for Out-of-Plane Tensile Test which refers to ASTM D7291. However, several modifications were required to perform the compression test. Fibers are generally oriented in two dimensions. The fiber grain direction is along two axes. However, no fibers are directly oriented in the direction of the third axis. The third axis will be known as the z-axis. A compressive force is applied at a rate of 0.05 in/min perpendicular to the fiber orientation. The test is performed on the MTS 311. Three longitudinal strain gauges are placed 120 degrees apart on the specimen (1L, 2L, and 3L) as shown below.

140°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Reference I-86 to I-90 for individual specimen test summary sheets and notes.
- 2) The failure mode “rupture” indicated the specimen failed by rupturing into two or more pieces at ultimate load.

Facing Researchers

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-01-140-FY-09**
 Test Date: 9/15/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 14,967 lbs
 Maximum Stress, SC_z : 26,703 psi
 Compressive Modulus, E_z : 718,533 psi
 Ultimate Strain, ϵ_z : 0.039 in/in

Measured Specimen Dimensions:

Length, L: 0.8206 in
 Diameter, D: 0.8448 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 2,993 psi
 50% Max Load: 7,483 psi

PICTURE OF SPECIMEN PRE-TEST



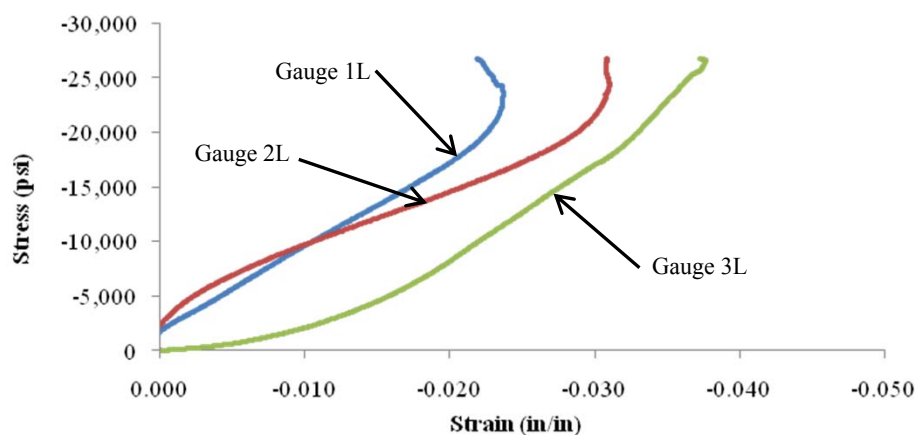
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01508 | -0.00463 | 766,805 |
| 2L | -0.01757 | -0.00276 | 540,768 |
| 3L | -0.02578 | -0.01633 | 848,025 |
| Average | | | 718,533 |

Stress-Strain Curve 140F_01_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-02-140-FY-09**
 Test Date: 9/15/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 15,523 lbs
 Maximum Stress, SC_z : 27,415 psi
 Compressive Modulus, E_z : 806,729 psi
 Ultimate Strain, ϵ_z : 0.035 in/in

Measured Specimen Dimensions:

Length, L: 0.7789 in
 Diameter, D: 0.8491 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 3,105 psi
 50% Max Load: 7,761 psi

PICTURE OF SPECIMEN PRE-TEST



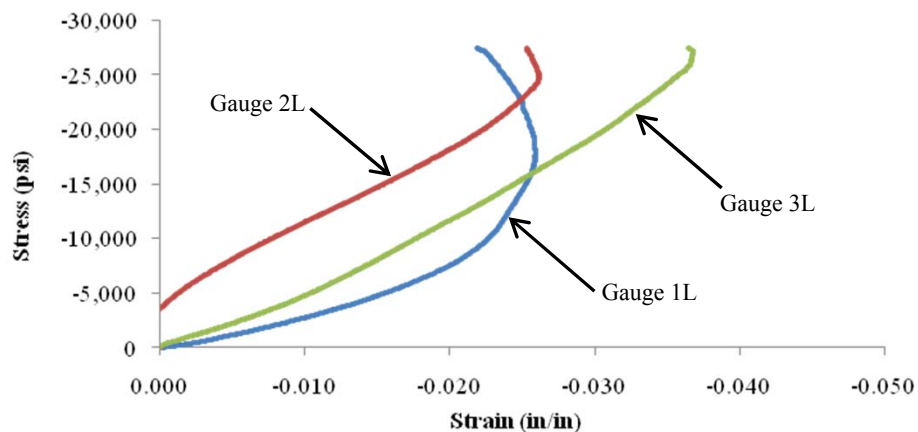
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02465 | -0.01650 | 1,009,899 |
| 2L | -0.01345 | 0.00175 | 702,659 |
| 3L | -0.02278 | -0.01116 | 707,628 |
| Average | | | 806,729 |

Stress-Strain Curve 140F_02_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-03-140-FY-09**
 Test Date: 9/15/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 14,972 lbs
 Maximum Stress, SC_z : 27,619 psi
 Compressive Modulus, E_z : 836,495 psi
 Ultimate Strain, ϵ_z : 0.033 in/in

Measured Specimen Dimensions:

Length, L: 0.7903 in
 Diameter, D: 0.8308 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 2,994 psi
 50% Max Load: 7,486 psi

PICTURE OF SPECIMEN PRE-TEST



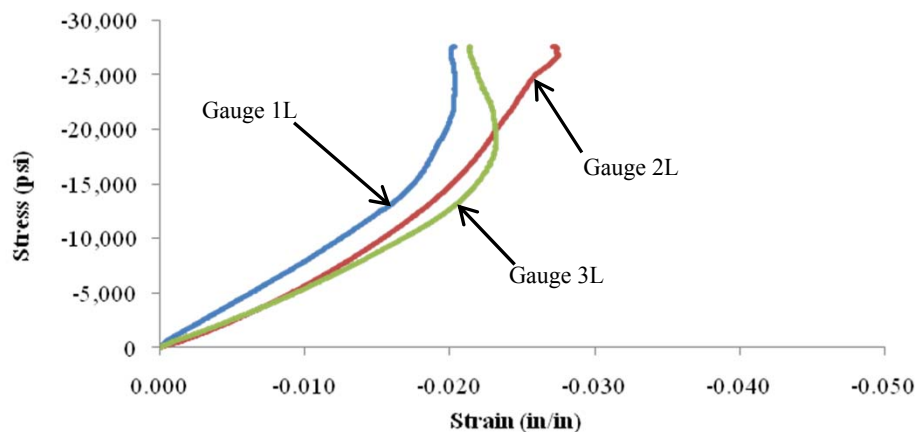
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01655 | -0.00693 | 861,009 |
| 2L | -0.01916 | -0.00978 | 883,986 |
| 3L | -0.02101 | -0.01017 | 764,489 |
| Average | | | 836,495 |

Stress-Strain Curve 140F_03_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness “Flatwise” Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-04-140-FY-09**
 Test Date: 9/15/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 15,110 lbs
 Maximum Stress, SC_z : 26,968 psi
 Compressive Modulus, E_z : 819,277 psi
 Ultimate Strain, ϵ_z : 0.033 in/in

Measured Specimen Dimensions:

Length, L: 0.8201 in
 Diameter, D: 0.8446 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 3,022 psi
 50% Max Load: 7,555 psi

PICTURE OF SPECIMEN PRE-TEST



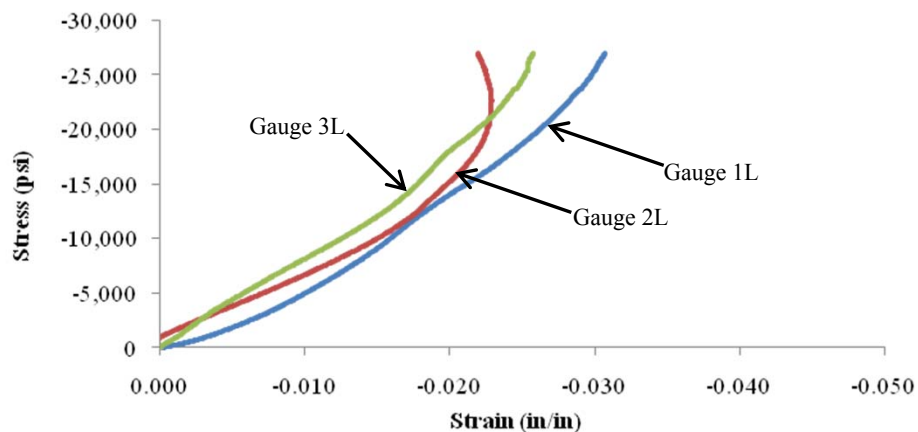
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.01936 | -0.01053 | 916,592 |
| 2L | -0.01856 | -0.00777 | 749,912 |
| 3L | -0.01648 | -0.00626 | 791,326 |
| Average | | | 819,277 |

Stress-Strain Curve 140F_04_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

TEST: Standard Test Method for Through-Thickness "Flatwise" Compressive Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*LTU Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-CZ-05-140-FY-09**
 Test Date: 9/15/2011
 Specimen Received: 7/21/2011
 Properties Measured: SC_z , E_z , ϵ_z

Average Material Properties:

Maximum Load, P_z : 14,747 lbs
 Maximum Stress, SC_z : 26,301 psi
 Compressive Modulus, E_z : 815,566 psi
 Ultimate Strain, ϵ_z : 0.034 in/in

Measured Specimen Dimensions:

Length, L: 0.8136 in
 Diameter, D: 0.8449 in
 Laboratory Temperature: 70°F
 Failure Mode: Rupture
 20% Max Load: 2,949 psi
 50% Max Load: 7,373 psi

PICTURE OF SPECIMEN PRE-TEST



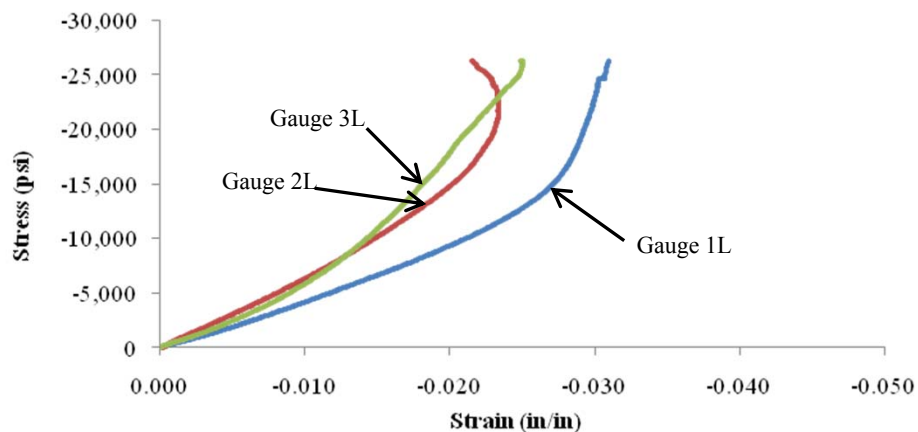
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | |
|---------------------|--|--|---------------------------------------|
| Gauge | Strain @ 50% Max Load ϵ_z (in/in) | Strain @ 20% Max Load ϵ_z (in/in) | Compressive Modulus E_z (psi) |
| 1L | -0.02537 | -0.01223 | 600,738 |
| 2L | -0.01832 | -0.00844 | 798,269 |
| 3L | -0.01678 | -0.00925 | 1,047,693 |
| Average | | | 815,566 |

Stress-Strain Curve 140F_05_(09-06)



Engineering Test notes:

- *Specimen was fitted with three Vishay CEA-06-125UW-350 strain gauges spaced 120° around the specimen.
- *Elastic Modulus was calculated using strain at 20% and 50% of max load.
- *Strain and load data were recorded using a Titan Mini-recorder (calibrated 6-3-10).

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-SXZ-N40-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**
 Nominal Temperature: **-40°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **767** **lbs**
 Shear Strength, S_{xz} : **5,052** **psi**
 Shear Modulus, G_{xz} : **363,312** **psi**

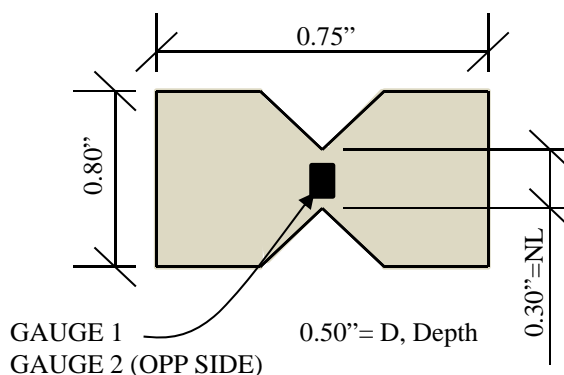
| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT6-SXZ-01-N40-FY09 | 830 | 5,512 | 352,973 | Shear |
| MAT6-SXZ-02-N40-FY09 | 678 | 4,423 | 359,962 | Shear |
| MAT6-SXZ-03-N40-FY09 | 727 | 4,775 | 363,854 | Shear |
| MAT6-SXZ-04-N40-FY09 | 908 | 5,999 | 355,442 | Shear |
| MAT6-SXZ-05-N40-FY09 | 692 | 4,550 | 379,330 | Shear |
| Average | 767 | 5,052 | 362,312 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

-40°F Temperature Condition**Notes:**

- 1) Individual specimen results are shown on Sheets I-92 to I-96
- 2) Six specimens tested, with 5 specimen results shown
- 3) All specimens tested failed in shear at the specimen notch

**Nominal Dimensions/
Strain Gauge Configuration****FACING RESEARCHERS**

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-01-N40-FY09
 Test Date: 4/19/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

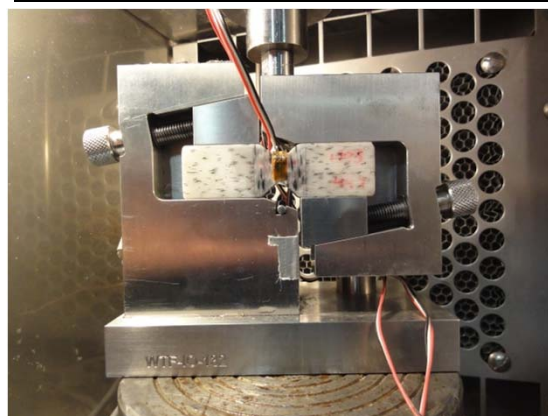
Average Material Properties:

Ultimate Load, P_{max} : 830 lbs
 Shear Strength, S_{xz} : 5,512 psi
 Shear Modulus, G_{xz} : 352,973 psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NL: 0.303 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 415 lbs
 20% Max Load: 166 lbs

PICTURE OF SPECIMEN PRE-TEST



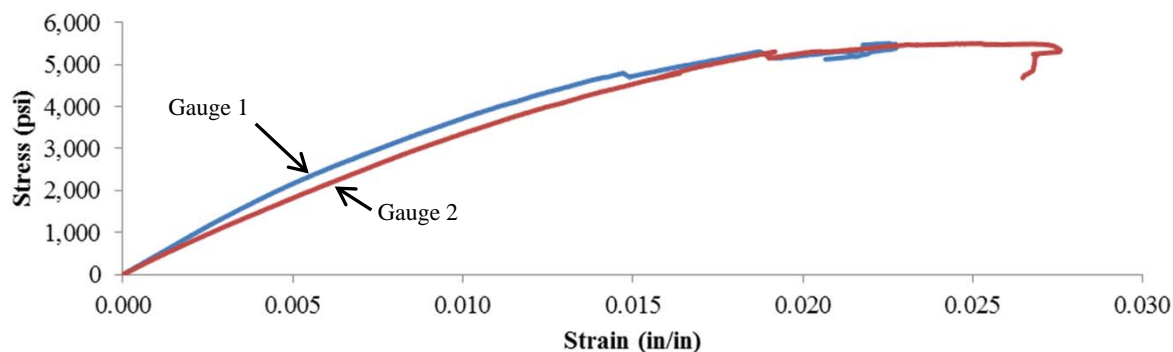
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0068 | 0.0024 | 377,205 |
| 2 | 0.0079 | 0.0029 | 328,742 |
| Average | | | 352,973 |

Stress-Strain Curve -40°F_1_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-02-N40-FY09
 Test Date: 4/19/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

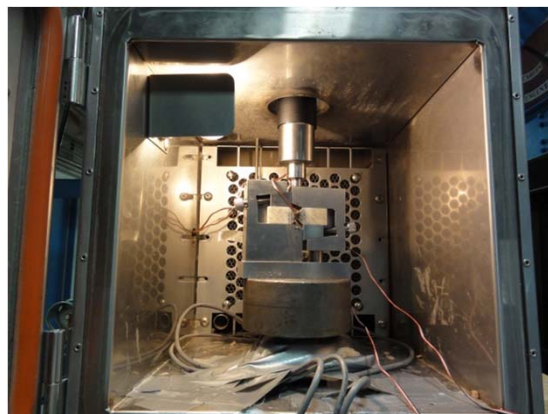
Average Material Properties:

Ultimate Load, P_{max} : 678 lbs
 Shear Strength, S_{xz} : 4,423 psi
 Shear Modulus, G_{xz} : 359,962 psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.309 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 339 lbs
 20% Max Load: 136 lbs

PICTURE OF SPECIMEN PRE-TEST



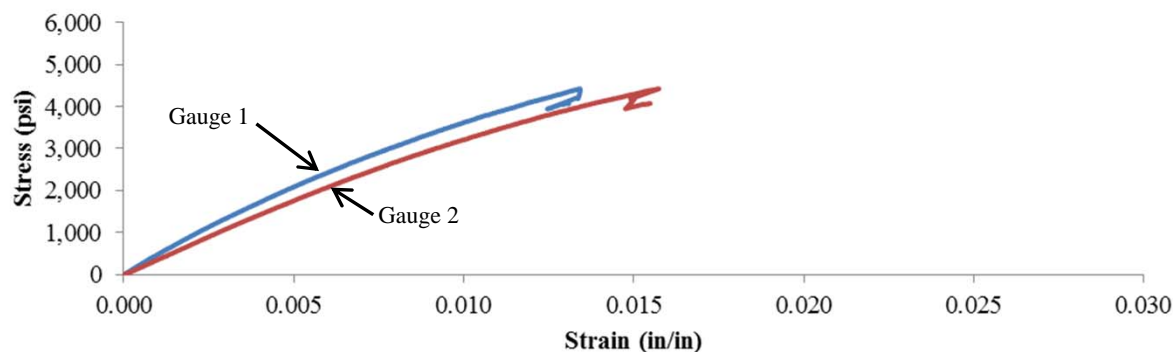
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0054 | 0.0019 | 385,256 |
| 2 | 0.0064 | 0.0025 | 334,668 |
| Average | | | 359,962 |

Stress-Strain Curve -40°F_2_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT6-SXZ-03-N40-FY09**
 Test Date: 4/19/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 727 lbs
Shear Strength, S_{xz} : 4,775 psi
Shear Modulus, G_{xz} : 363,854 psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.307 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 364 lbs
 20% Max Load: 145 lbs

PICTURE OF SPECIMEN PRE-TEST



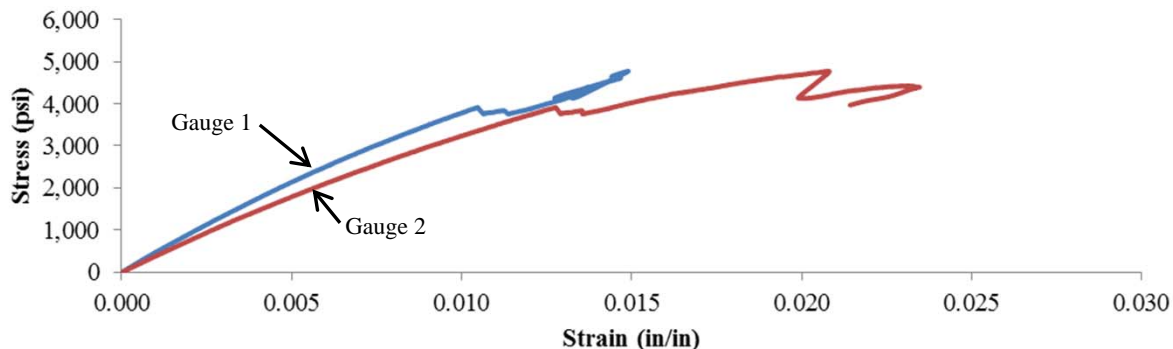
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0057 | 0.0021 | 400,834 |
| 2 | 0.0069 | 0.0025 | 326,873 |
| Average | | | 363,854 |

Stress-Strain Curve -40°F_3_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-04-N40-FY09
 Test Date: 4/20/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 908 lbs
 Shear Strength, S_{xz} : 5,999 psi
 Shear Modulus, G_{xz} : 355,442 psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.305 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 454 lbs
 20% Max Load: 182 lbs

PICTURE OF SPECIMEN PRE-TEST



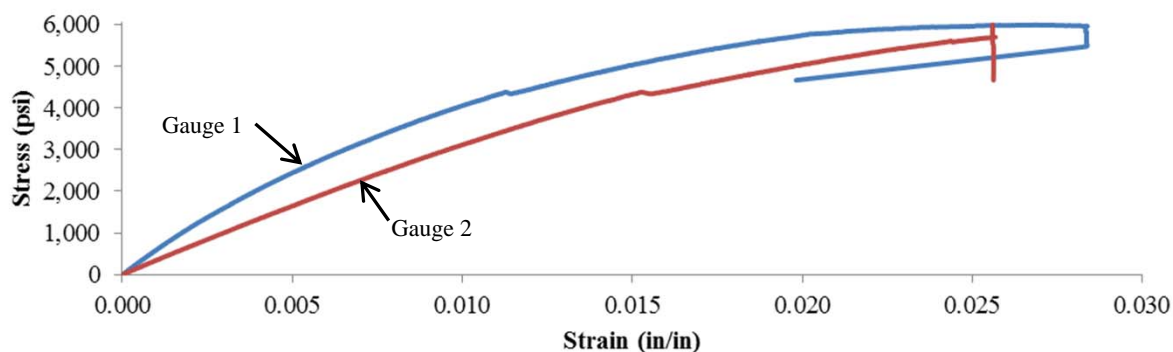
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0065 | 0.0021 | 409,543 |
| 2 | 0.0095 | 0.0036 | 301,341 |
| Average | | | 355,442 |

Stress-Strain Curve -40°F_4_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-05-N40-FY09
 Test Date: 4/20/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 692 lbs
 Shear Strength, S_{xz} : 4,550 psi
 Shear Modulus, G_{xz} : 379,330 psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NL: 0.306 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 346 lbs
 20% Max Load: 138 lbs

PICTURE OF SPECIMEN PRE-TEST



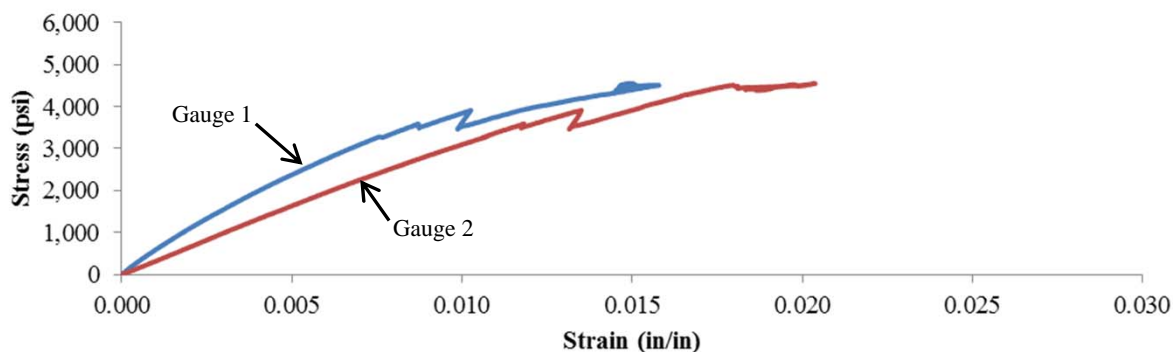
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0047 | 0.0016 | 440,524 |
| 2 | 0.0070 | 0.0028 | 318,136 |
| Average | | | 379,330 |

Stress-Strain Curve -40°F_5_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

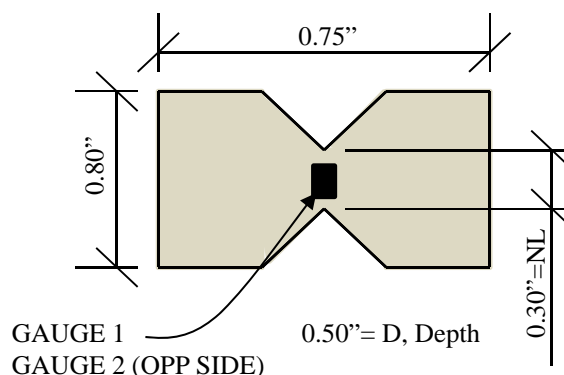
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-SXZ-70-FY09**
 Material: **Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric**
 Nominal Temperature: **70°F**
 Properties Measured: **G_{xz} , S_{xz}**
 Average Material Properties (5 Specimens):
 Ultimate Load, P_{max} : **507** **lbs**
 Shear Strength, S_{xz} : **3,400** **psi**
 Shear Modulus, G_{xz} : **273,895** **psi**

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|---------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT6-SXZ-01-70-FY09 | 513 | 3,436 | 264,471 | Shear |
| MAT6-SXZ-02-70-FY09 | 507 | 3,398 | 271,123 | Shear |
| MAT6-SXZ-03-70-FY09 | 492 | 3,270 | 271,584 | Shear |
| MAT6-SXZ-04-70-FY09 | 510 | 3,444 | 245,745 | Shear |
| MAT6-SXZ-05-70-FY09 | 512 | 3,449 | 316,553 | Shear |
| Average | 507 | 3,400 | 273,895 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

70°F Temperature Test Condition**Nominal Dimensions/
Strain Gauge Configuration****Notes:**

- 1) Individual specimen results are shown on Sheets I-98 to I-102
- 2) Five specimens tested, with all relevant data shown
- 3) All specimens tested failed in shear at the specimen notch

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-01-70-FY09
 Test Date: 3/16/12
 Specimen Received: 8/31/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 513 lbs
 Shear Strength, S_{xz} : 3,436 psi
 Shear Modulus, G_{xz} : 264,471 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.298 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 256 lbs
 20% Max Load: 103 lbs

PICTURE OF SPECIMEN PRE-TEST



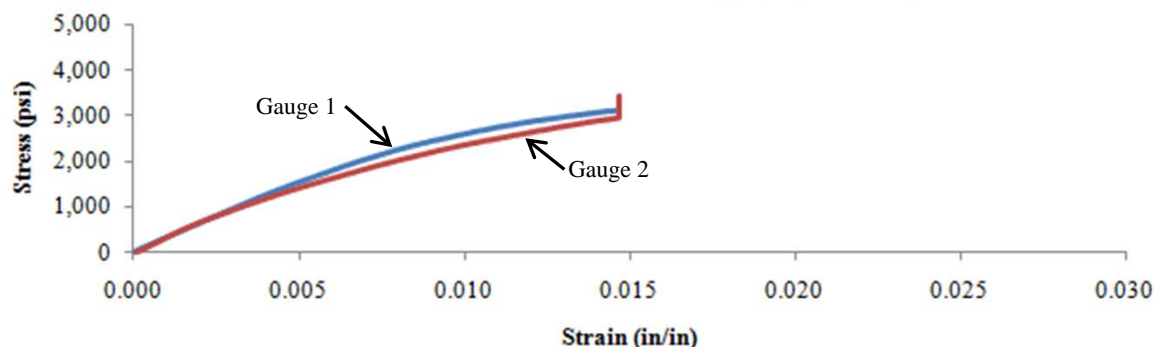
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0057 | 0.0021 | 291,133 |
| 2 | 0.0064 | 0.0021 | 237,808 |
| Average | | | 264,471 |

Stress-Strain Curve 70°F_1_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-02-70-FY09
 Test Date: 3/16/12
 Specimen Received: 8/31/11
 Properties Measured: S_{xz} , G_{xz}

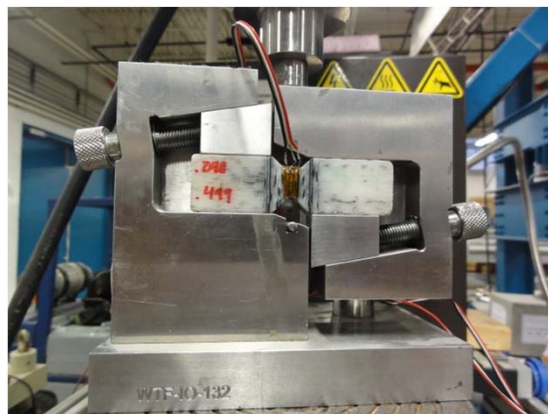
Average Material Properties:

Ultimate Load, P_{max} : 507 lbs
 Shear Strength, S_{xz} : 3,398 psi
 Shear Modulus, G_{xz} : 271,123 psi

Measured Specimen Dimensions:

Depth, D: 0.501 in
 Notch Length, NL: 0.298 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 254 lbs
 20% Max Load: 101 lbs

PICTURE OF SPECIMEN PRE-TEST



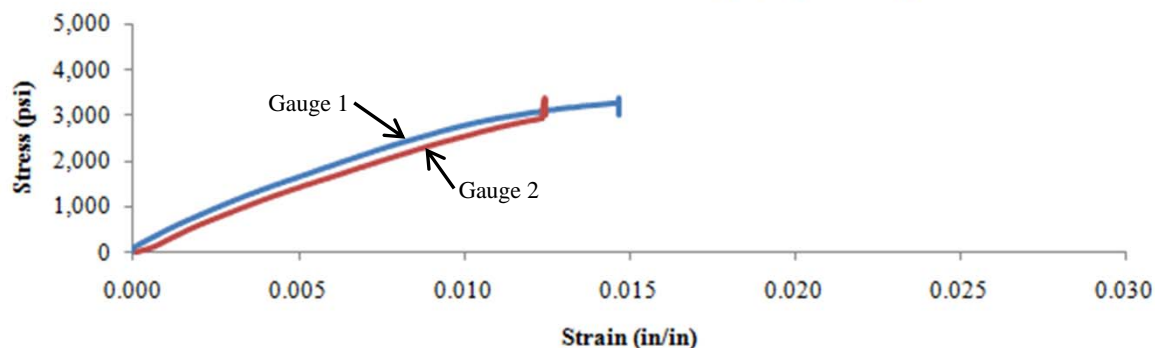
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0052 | 0.0016 | 282,526 |
| 2 | 0.0062 | 0.0023 | 259,720 |
| Average | | | 271,123 |

Stress-Strain Curve 70°F_2_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-03-70-FY09
 Test Date: 3/16/12
 Specimen Received: 8/31/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 492 lbs
 Shear Strength, S_{xz} : 3,270 psi
 Shear Modulus, G_{xz} : 271,584 psi

Measured Specimen Dimensions:

Depth, D: 0.498 in
 Notch Length, NL: 0.302 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 246 lbs
 20% Max Load: 98 lbs

PICTURE OF SPECIMEN PRE-TEST



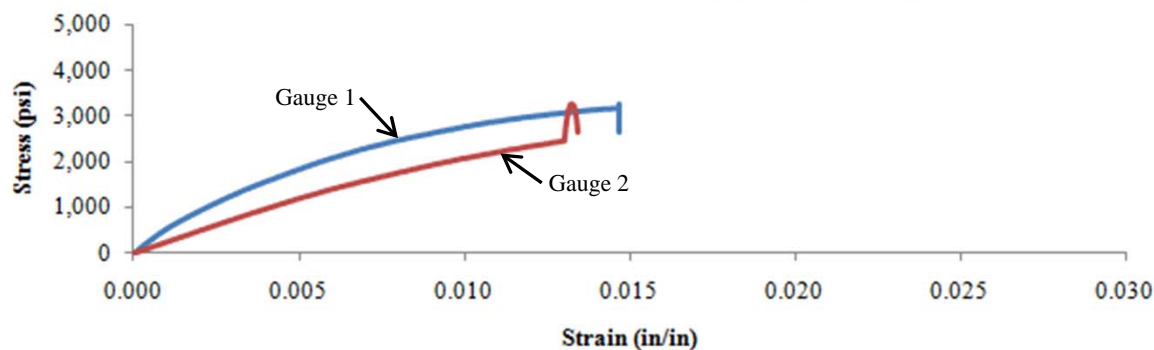
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0042 | 0.0013 | 331,016 |
| 2 | 0.0073 | 0.0027 | 212,153 |
| Average | | | 271,584 |

Stress-Strain Curve 70°F_3_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-04-70-FY09
 Test Date: 3/16/12
 Specimen Received: 8/31/11
 Properties Measured: S_{xz} , G_{xz}

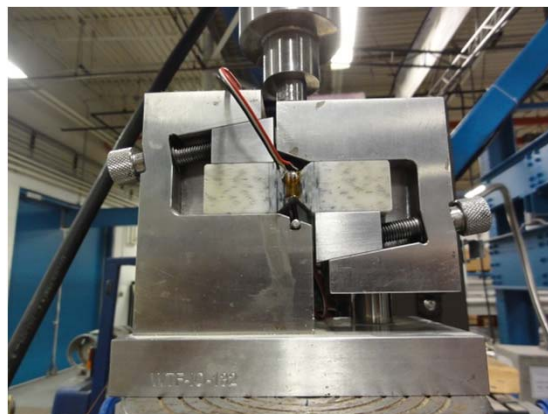
Average Material Properties:

Ultimate Load, P_{max} : 510 lbs
 Shear Strength, S_{xz} : 3,444 psi
 Shear Modulus, G_{xz} : 245,745 psi

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NL: 0.298 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 255 lbs
 20% Max Load: 102 lbs

PICTURE OF SPECIMEN PRE-TEST



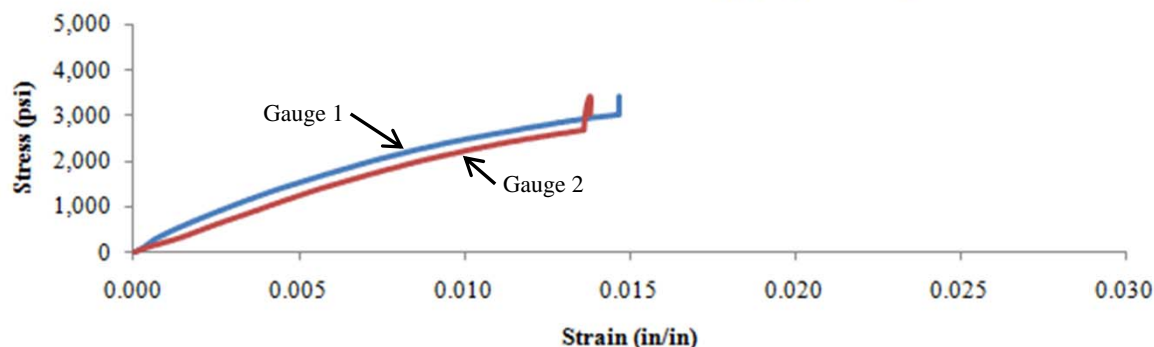
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0059 | 0.0018 | 256,348 |
| 2 | 0.0072 | 0.0028 | 235,142 |
| Average | | | 245,745 |

Stress-Strain Curve 70°F_4_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-05-70-FY09
 Test Date: 3/19/12
 Specimen Received: 8/31/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 512 lbs
 Shear Strength, S_{xz} : 3,449 psi
 Shear Modulus, G_{xz} : 316,553 psi

Measured Specimen Dimensions:

Depth, D: 0.496 in
 Notch Length, NL: 0.299 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 256 lbs
 20% Max Load: 102 lbs

PICTURE OF SPECIMEN PRE-TEST



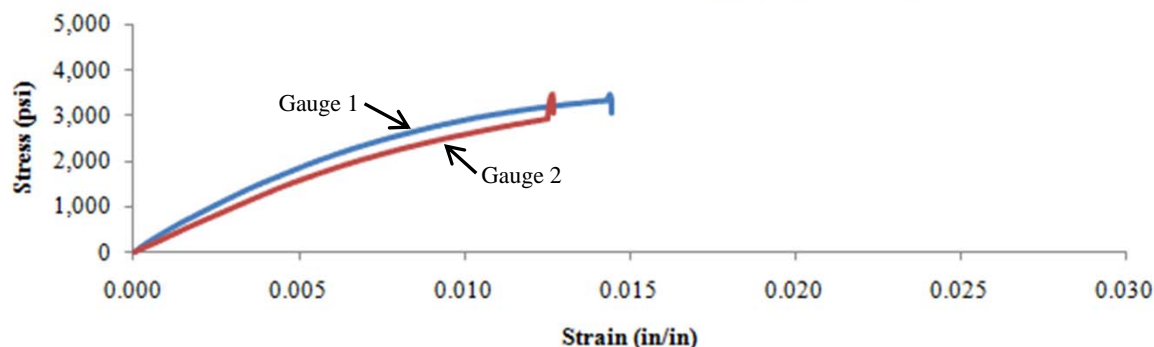
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0046 | 0.0015 | 339,487 |
| 2 | 0.0056 | 0.0021 | 293,619 |
| Average | | | 316,553 |

Stress-Strain Curve 70°F_5_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

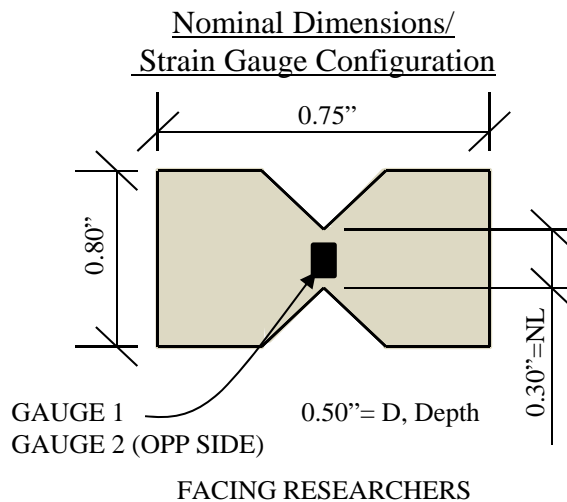
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: MAT6-SXZ-140-FY09
Material: Huntsman PolyUrethane (PU) Rencast 6405, Ductile Hybrid Fabric
Nominal Temperature: 140°F
Properties Measured: G_{xz} , S_{xz}
Average Material Properties (5 Specimens):
Ultimate Load, P_{max} : 212 lbs
Shear Strength, S_{xz} : 1,417 psi
Shear Modulus, G_{xz} : 79,668 psi

| Specimen | Ultimate Load, P_{max} (lb) | Shear Strength, S_{xz} (psi) | Shear Modulus, G_{xz} (psi) | Failure Mode |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|--------------|
| MAT6-SXZ-01-140-FY09 | 225 | 1,496 | 86,972 | Shear |
| MAT6-SXZ-02-140-FY09 | 182 | 1,215 | 67,089 | Shear |
| MAT6-SXZ-03-140-FY09 | 271 | 1,827 | 114,075 | Shear |
| MAT6-SXZ-04-140-FY09 | 200 | 1,338 | 68,198 | Shear |
| MAT6-SXZ-05-140-FY09 | 182 | 1,209 | 62,005 | Shear |
| Average | 212 | 1,417 | 79,668 | |

Test Description:

The V-Notch Shear Beam Method Test, performed within the guidelines of ASTM D5379 measures the shear properties of fiber reinforced polymer matrix composite materials. This test reports the shear strength and shear modulus resulted by an inter-laminar shear load applied to the 'x' and 'z' material plane. The test is performed on the Instron 8502A testing machine. Two strain gauges are applied, one on each side of the specimen, at the center of the V-notch. A displacement rate of 0.010 in/min is used for data acquisition. The ultimate load is the lower of the ultimate load or the load at 5% shear strain which is then used to calculate the ultimate shear strength. The standard for this test recommends calculating a shear "chord" modulus but due to exclusive material properties (strain ranges) and engineering judgment, a general shear modulus was calculated. The shear modulus was generated using the linear region at 20-50% of the maximum load.

140°F Temperature Test Condition**Notes:**

- 1) Individual specimen results are shown on Sheets I-104 to I-108
- 2) Ten specimens tested, with 5 specimen results shown.
- 3) All specimens tested failed in shear

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-01-140-FY09
 Test Date: 3/20/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

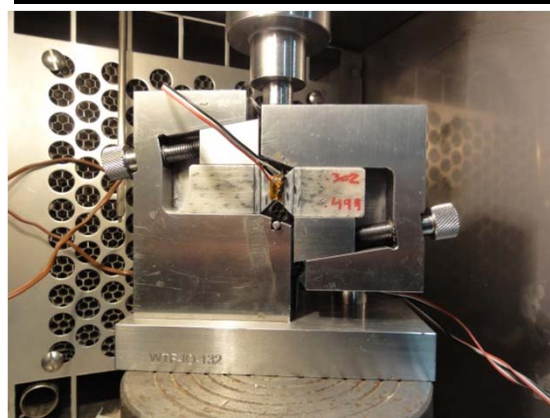
Average Material Properties:

Ultimate Load, P_{max} : 225 lbs
 Shear Strength, S_{xz} : 1,496 psi
 Shear Modulus, G_{xz} : 86,972 psi

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.302 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 113 lbs
 20% Max Load: 45 lbs

PICTURE OF SPECIMEN PRE-TEST



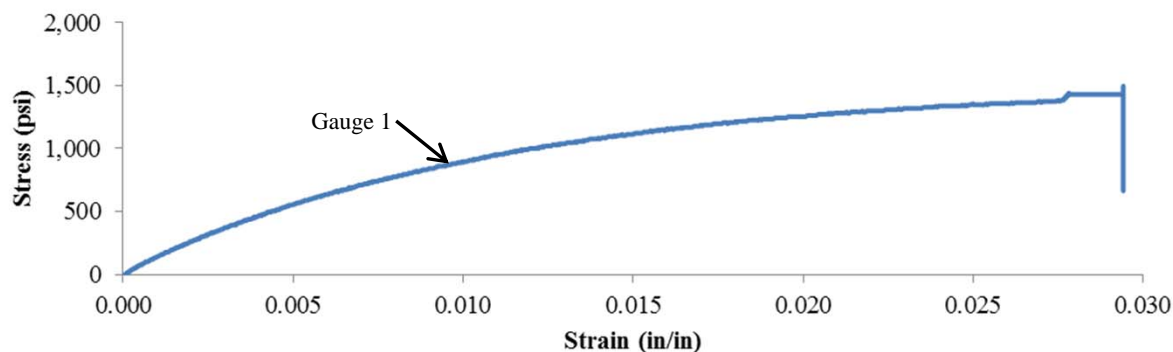
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0075 | 0.0024 | 86,972 |
| 2 | Lost Gauge | Lost Gauge | - |
| Average | | | 86,972 |

Stress-Strain Curve 140°F_1_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-02-140-FY09
 Test Date: 3/20/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

Average Material Properties:

Ultimate Load, P_{max} : 182 lbs
 Shear Strength, S_{xz} : 1,215 psi
 Shear Modulus, G_{xz} : 67,089 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.298 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 91 lbs
 20% Max Load: 36 lbs

PICTURE OF SPECIMEN PRE-TEST



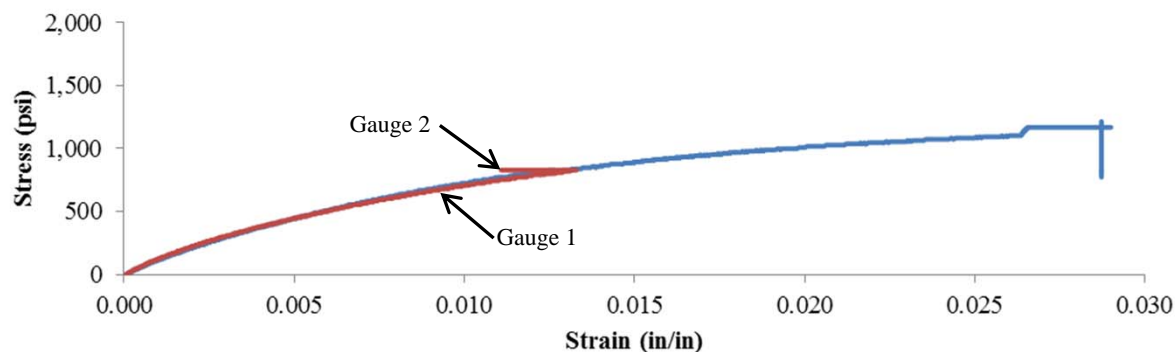
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0076 | 0.0023 | 69,253 |
| 2 | 0.0078 | 0.0022 | 64,925 |
| Average | | | 67,089 |

Stress-Strain Curve 140°F_2_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-03-140-FY09
 Test Date: 4/10/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

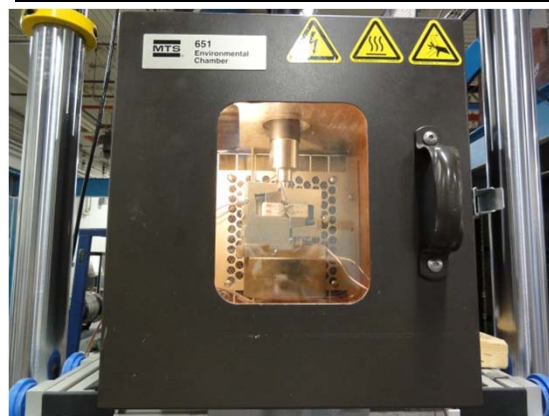
Average Material Properties:

Ultimate Load, P_{max} : 271 lbs
 Shear Strength, S_{xz} : 1,827 psi
 Shear Modulus, G_{xz} : 114,075 psi

Measured Specimen Dimensions:

Depth, D: 0.502 in
 Notch Length, NL: 0.295 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 135 lbs
 20% Max Load: 54 lbs

PICTURE OF SPECIMEN PRE-TEST



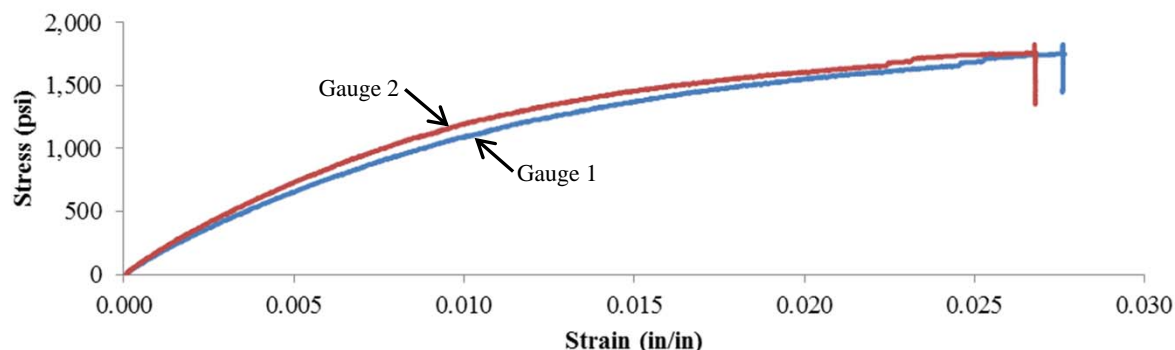
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0076 | 0.0024 | 105,892 |
| 2 | 0.0066 | 0.0021 | 122,258 |
| Average | | | 114,075 |

Stress-Strain Curve 140°F_3_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: **MAT6-SXZ-04-140-FY09**
 Test Date: 4/10/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

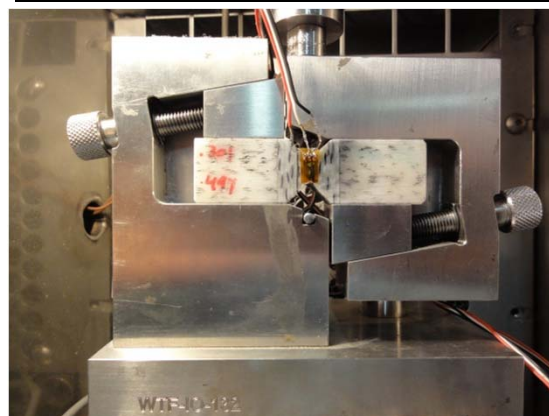
Average Material Properties:

Ultimate Load, P_{max} : **200** **lbs**
Shear Strength, S_{xz} : **1,338** **psi**
Shear Modulus, G_{xz} : **68,198** **psi**

Measured Specimen Dimensions:

Depth, D: 0.497 in
 Notch Length, NL: 0.301 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 100 lbs
 20% Max Load: 40 lbs

PICTURE OF SPECIMEN PRE-TEST



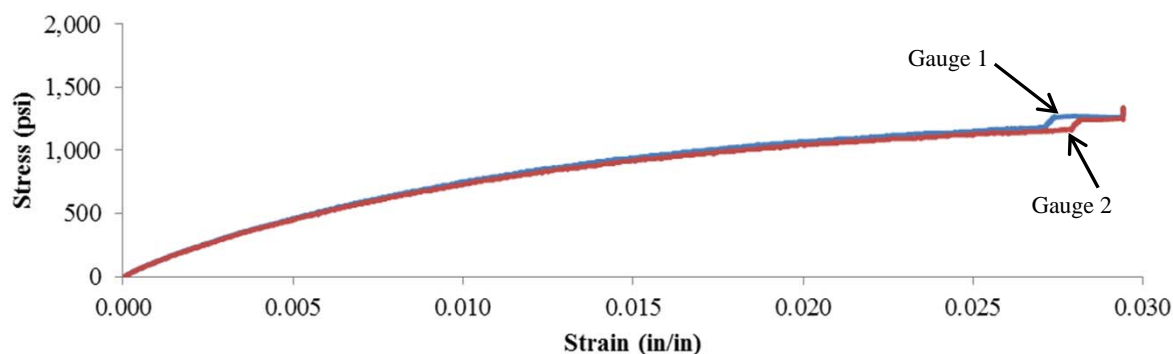
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0083 | 0.0025 | 69,555 |
| 2 | 0.0086 | 0.0026 | 66,841 |
| Average | | | 68,198 |

Stress-Strain Curve 140°F_4_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method (ASTM D5379/ D5379M-05)

Individual Specimen Test Summary

Specimen ID: MAT6-SXZ-05-140-FY09
 Test Date: 4/12/12
 Specimen Received: 7/7/11
 Properties Measured: S_{xz} , G_{xz}

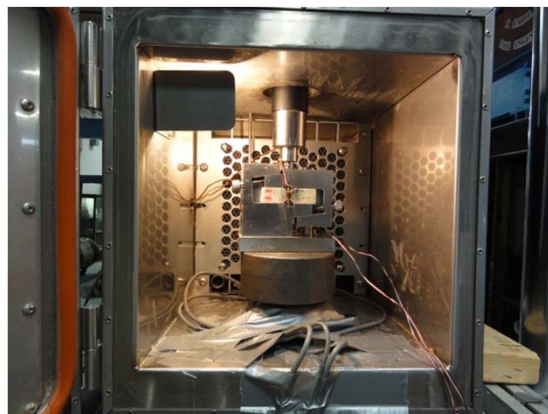
Average Material Properties:

Ultimate Load, P_{max} : 182 lbs
 Shear Strength, S_{xz} : 1,209 psi
 Shear Modulus, G_{xz} : 62,005 psi

Measured Specimen Dimensions:

Depth, D: 0.499 in
 Notch Length, NL: 0.302 in
 Laboratory Temperature: 70°F
 Failure Mode: Shear
 50% Max Load: 91 lbs
 20% Max Load: 36 lbs

PICTURE OF SPECIMEN PRE-TEST



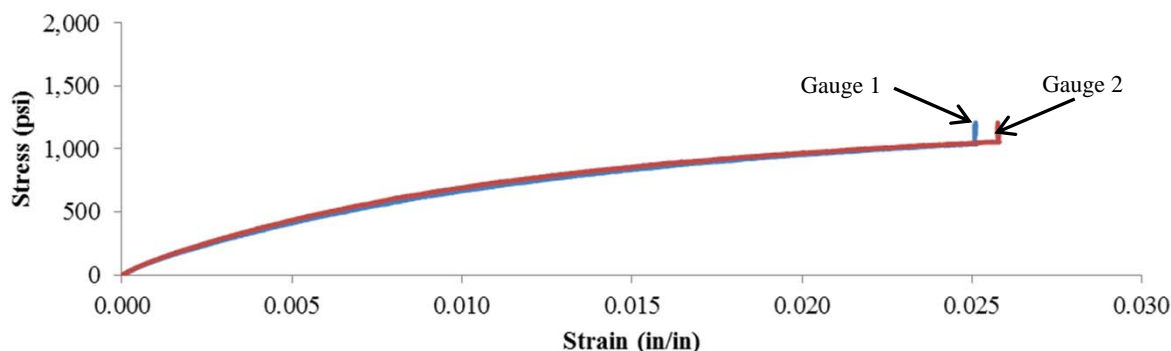
PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Strain Gauges | | | |
|----------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Gauge | Strain @ 50% Max Load (in/in) | Strain @ 20% Max Load (in/in) | Shear Modulus, G_{xz} (psi) |
| 1 | 0.0085 | 0.0025 | 59,896 |
| 2 | 0.0080 | 0.0023 | 64,114 |
| Average | | | 62,005 |

Stress-Strain Curve 140°F_5_(09-06)



Engineering Test notes:

- *Specimen was fitted with two Vishay CEA-06-062UV-350 strain gauges (one on each side)
- *Shear Modulus was calculated using the linear region at 20-50% of the maximum load
- *Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

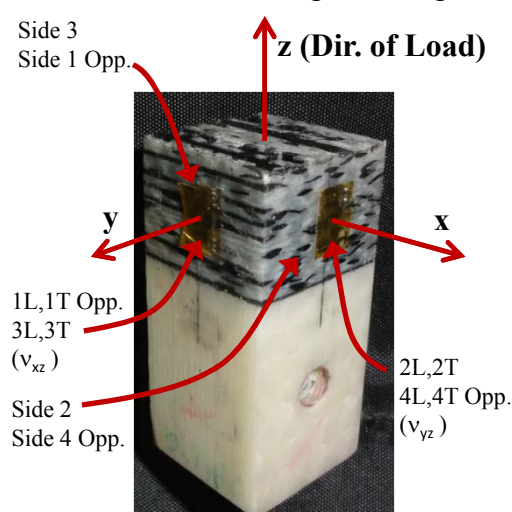
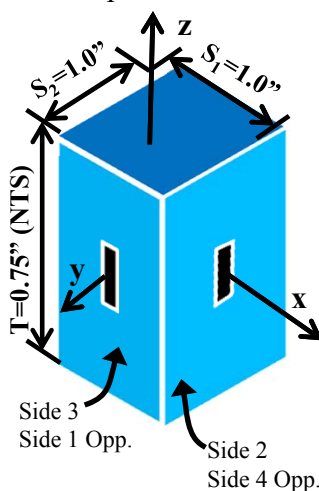
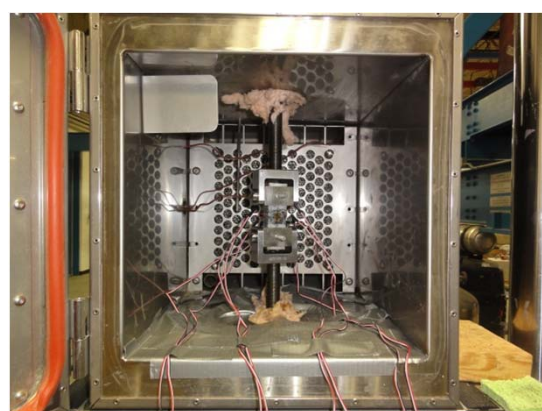
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-OP-N40-FY09**
 Material: **Huntsman Epoxies Rn 8605, Ductile Hybrid Fabric**
 Nominal Temperature: **-40°F**
 Properties Measured:
 Average Material Properties (5 Specimens): ^{1, 2}
 Poisson’s Ratio, ν_{xz} : **0.0517**
 Poisson’s Ratio, ν_{yz} : **0.2081**

| Specimen | Max Stress, σ_z ³ (psi) | Tensile Modulus, E_z (psi) | Poisson’s Ratio | | Failure Mode ⁴ |
|--------------------|--|---------------------------------|-----------------|---------------|---------------------------|
| | | | ν_{xz} | ν_{yz} | |
| MAT6-OP-1-N40-FY09 | 3,595 | 1,175,402 | 0.0806 | 0.2473 | Bondline |
| MAT6-OP-2-N40-FY09 | 2,381 | 1,301,281 | 0.0428 | 0.2956 | Bondline |
| MAT6-OP-3-N40-FY09 | 2,641 | 1,053,168 | 0.0398 | 0.1420 | Bondline |
| MAT6-OP-4-N40-FY09 | 2,821 | 1,168,205 | 0.0410 | 0.1585 | Bondline |
| MAT6-OP-5-N40-FY09 | 2,852 | 1,155,801 | 0.0544 | 0.1973 | Rupture |
| Average | 2,858 | 1,170,771 | 0.0517 | 0.2081 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Dissimilar from other materials part of this research, the ν_{xz} and ν_{yz} Poisson’s ratio results varied significantly for Material 6-FY09 (often negative). Therefore, strain gauges are used to measure longitudinal and transverse strain on all four sides of the specimen. Two are used to measure ν_{xz} and two are used to measure ν_{yz} . The orientation of each axis is shown with a picture of a specimen which also indicates which property is measured on each of the four sides. As shown in the picture, horizontal black lines are evident on Sides 1 and 3.

-40°F Temperature Test ConditionNominal Specimen DimensionsPicture, Strain Gauges Config.**Notes:**

- 1) Reference I-110 thru I-114 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Max stress achieved during each test.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 5) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-1-N40-FY09**
 Test Date: 2/29/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

Average Material Properties:

Maximum Stress, σ_z :¹ 3,206 psi
 Poisson’s Ratio, v_{xz} : 0.0806
 Poisson’s Ratio, v_{yz} : 0.2473

Specimen Data:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.998 in
 Test Max Stress:² 3,595 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST

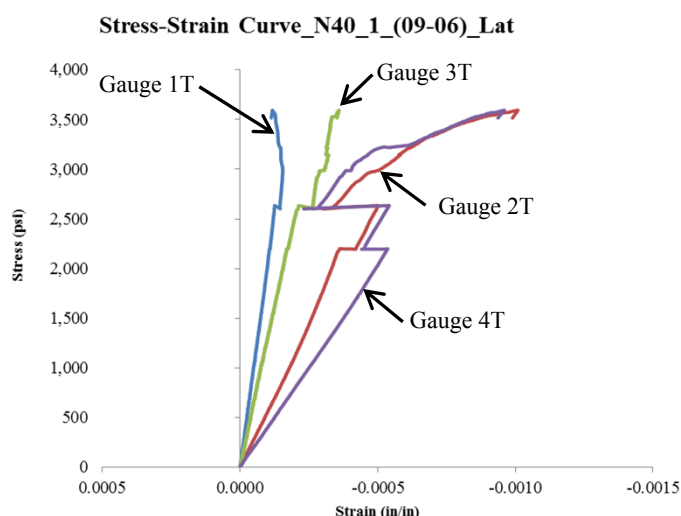
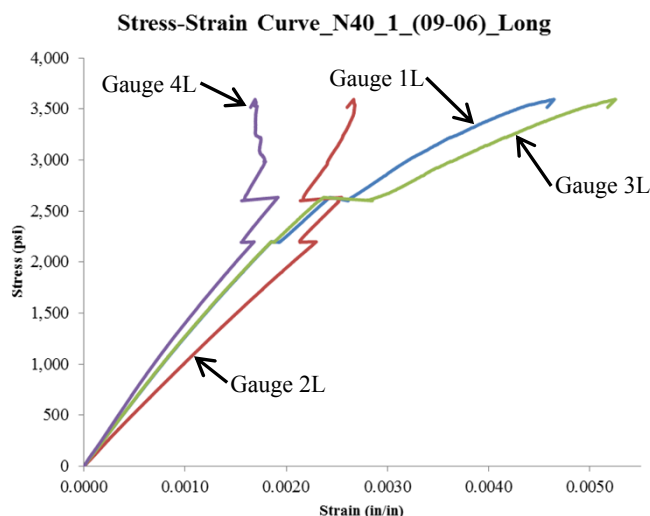


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson’s Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001295 | 0.000494 | 1,200,620 | 1T (x) | -0.000080 | -0.000031 | 0.0618 |
| 2L | 0.001620 | 0.000621 | 962,241 | 2T (y) | -0.000276 | -0.000115 | 0.1610 |
| 3L | 0.001287 | 0.000492 | 1,210,916 | 3T (x) | -0.000126 | -0.000047 | 0.0993 |
| 4L | 0.001163 | 0.000439 | 1,327,832 | 4T (y) | -0.000401 | -0.000160 | 0.3335 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0806 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.2473 |



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-N40-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson’s Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-N40-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-2-N40-FY09**
 Test Date: 3/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

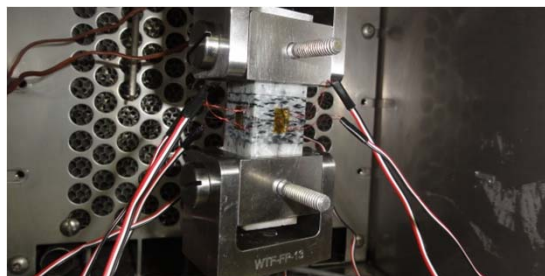
Average Material Properties:

Maximum Stress, σ_z :¹ 3,206 psi
 Poisson's Ratio, v_{xz} : 0.0428
 Poisson's Ratio, v_{yz} : 0.2956

Specimen Data:

Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.997 in
 Test Max Stress:² 2,381 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



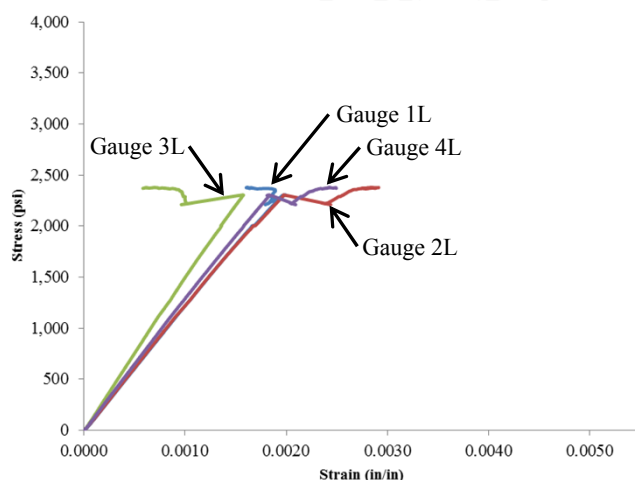
PICTURE OF SPECIMEN POST-TEST



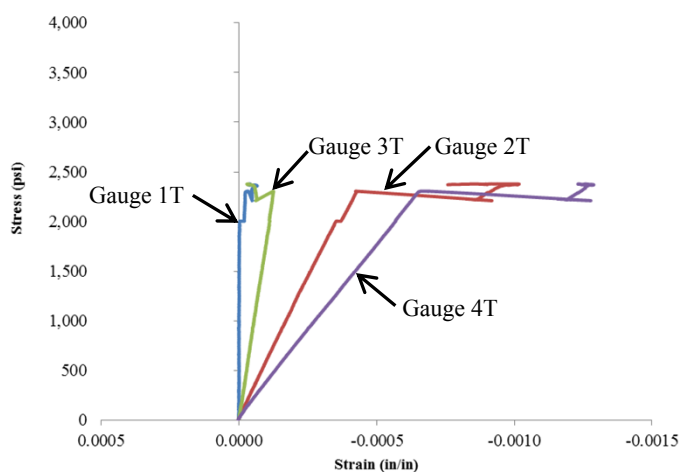
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001319 | 0.000532 | 1,221,391 | 1T (x) | 0.000000 | 0.000000 | 0.0011 |
| 2L | 0.001318 | 0.000526 | 1,215,085 | 2T (y) | -0.000278 | -0.000106 | 0.2179 |
| 3L | 0.001072 | 0.000428 | 1,493,577 | 3T (x) | -0.000089 | -0.000034 | 0.0844 |
| 4L | 0.001251 | 0.000497 | 1,275,071 | 4T (y) | -0.000452 | -0.000170 | 0.3733 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0428 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.2956 |

Stress-Strain Curve_N40_2_(09-06)_Long



Stress-Strain Curve_N40_2_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-N40-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-N40-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-3-N40-FY09**
 Test Date: 3/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

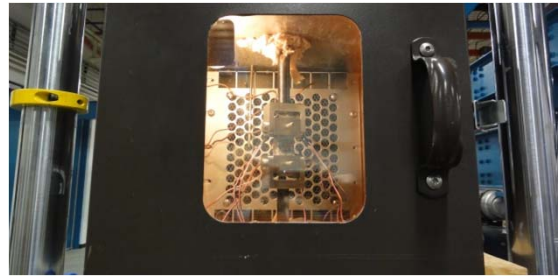
Average Material Properties:

Maximum Stress, σ_z :¹ 3,206 psi
 Poisson's Ratio, v_{xz} : 0.0398
 Poisson's Ratio, v_{yz} : 0.1420

Specimen Data:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 0.996 in
 Test Max Stress:² 2,641 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



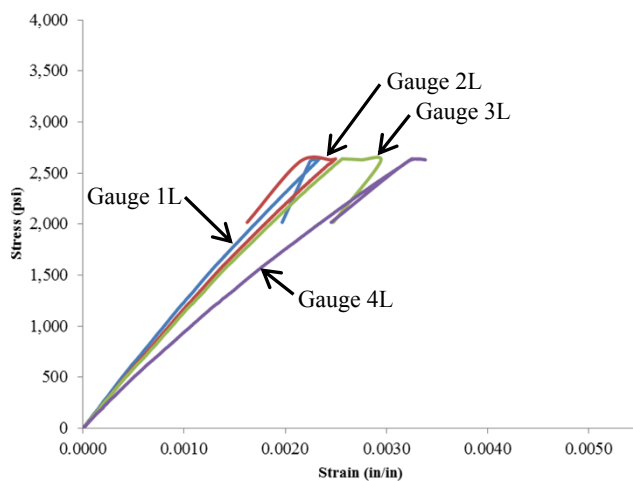
PICTURE OF SPECIMEN POST-TEST



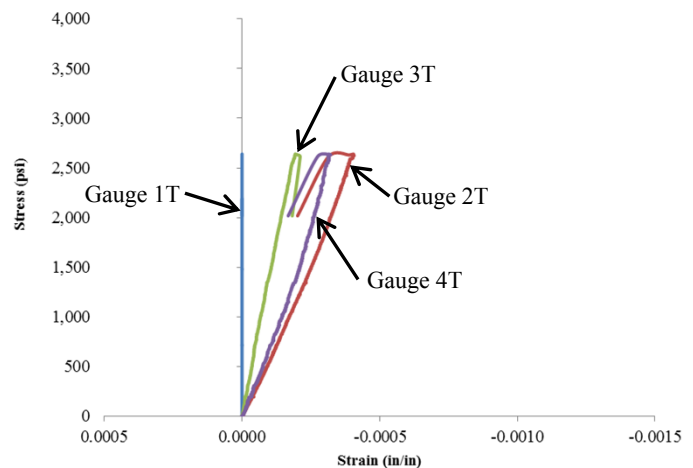
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001321 | 0.000502 | 1,173,998 | 1T (x) | 0.000000 | 0.000000 | 0.0000 |
| 2L | 0.001398 | 0.000537 | 1,116,443 | 2T (y) | -0.000265 | -0.000114 | 0.1755 |
| 3L | 0.001444 | 0.000553 | 1,079,456 | 3T (x) | -0.000114 | -0.000043 | 0.0796 |
| 4L | 0.001799 | 0.000658 | 842,775 | 4T (y) | -0.000218 | -0.000094 | 0.1086 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0398 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.1420 |

Stress-Strain Curve_N40_3_(09-06)_Long



Stress-Strain Curve_N40_3_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-N40-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-N40-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-4-N40-FY09**
 Test Date: 4/2/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

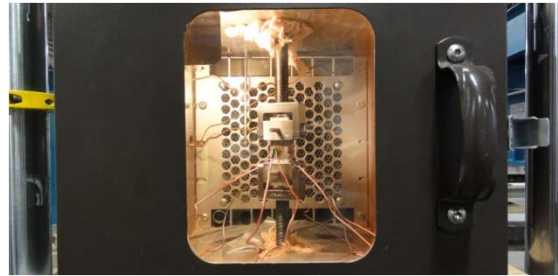
Average Material Properties:

Maximum Stress, σ_z :¹ 3,206 psi
 Poisson's Ratio, v_{xz} : 0.0410
 Poisson's Ratio, v_{yz} : 0.1585

Specimen Data:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 0.998 in
 Test Max Stress:² 2,821 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



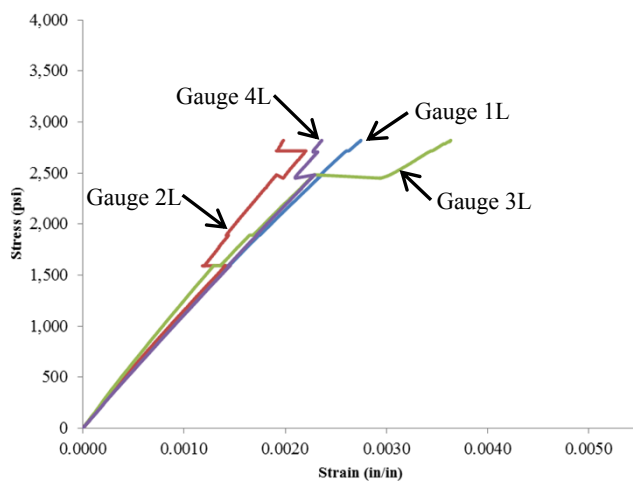
PICTURE OF SPECIMEN POST-TEST



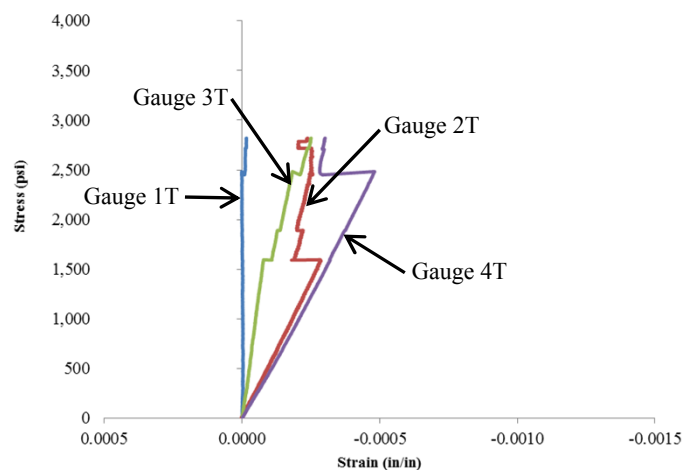
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001456 | 0.000550 | 1,061,069 | 1T (x) | -0.000001 | -0.000004 | -0.0034 |
| 2L | 0.001212 | 0.000532 | 1,414,758 | 2T (y) | -0.000192 | -0.000118 | 0.1096 |
| 3L | 0.001367 | 0.000493 | 1,100,776 | 3T (x) | -0.000108 | -0.000033 | 0.0854 |
| 4L | 0.001445 | 0.000568 | 1,096,218 | 4T (y) | -0.000319 | -0.000137 | 0.2074 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0410 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.1585 |

Stress-Strain Curve_N40_4_(09-06)_Long



Stress-Strain Curve_N40_4_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-N40-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-N40-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-5-N40-FY09**
 Test Date: 4/4/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

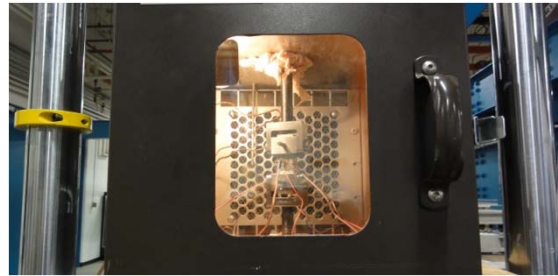
Average Material Properties:

Maximum Stress, σ_z : ¹ 3,206 psi
 Poisson's Ratio, v_{xz} : 0.0544
 Poisson's Ratio, v_{yz} : 0.1973

Specimen Data:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.996 in
 Test Max Stress: ² 2,852 psi
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



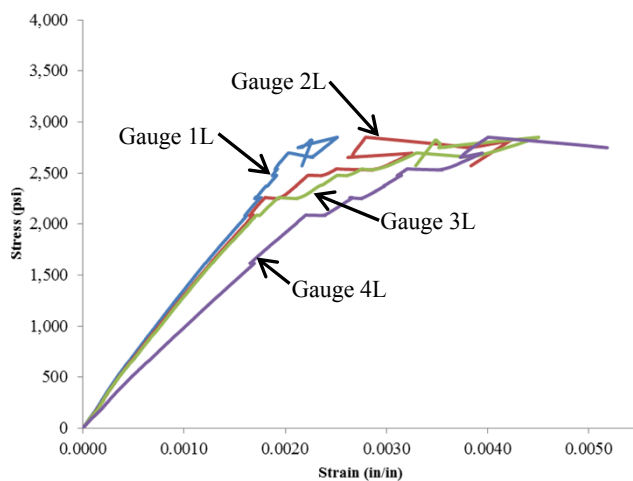
PICTURE OF SPECIMEN POST-TEST



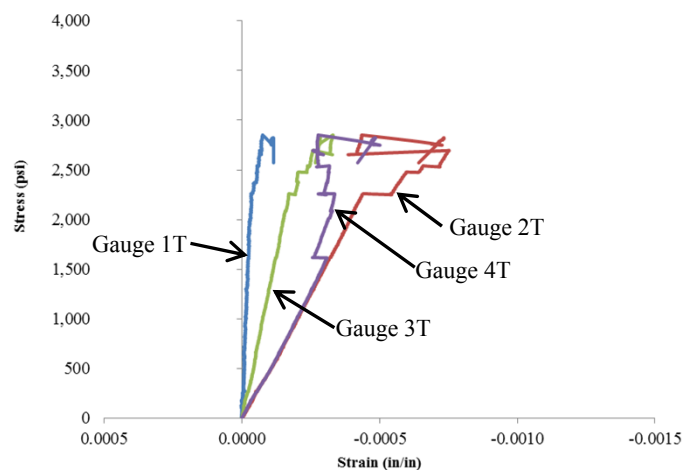
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001197 | 0.000442 | 1,275,071 | 1T (x) | -0.000023 | -0.000008 | 0.0191 |
| 2L | 0.001252 | 0.000463 | 1,219,282 | 2T (y) | -0.000315 | -0.000134 | 0.2291 |
| 3L | 0.001263 | 0.000471 | 1,214,388 | 3T (x) | -0.000121 | -0.000050 | 0.0897 |
| 4L | 0.001680 | 0.000629 | 914,461 | 4T (y) | -0.000307 | -0.000132 | 0.1656 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0544 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.1973 |

Stress-Strain Curve_N40_5_(09-06)_Long



Stress-Strain Curve_N40_5_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-N40-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-N40-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

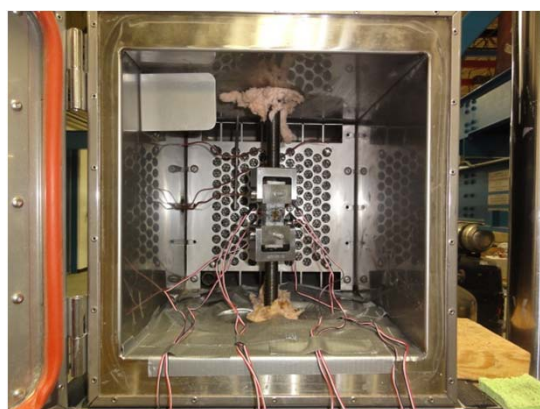
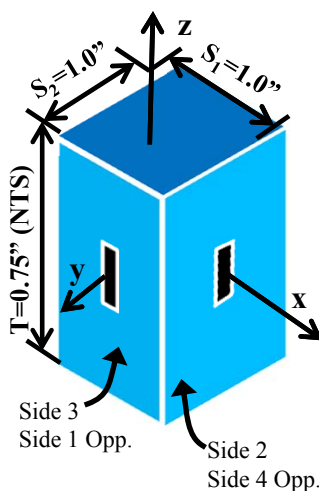
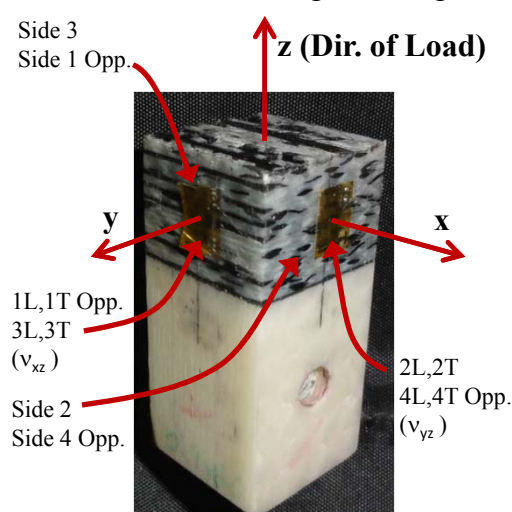
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-OP-70-FY09**
 Material: **Huntsman Epoxies Rn 8605, Ductile Hybrid Fabric**
 Nominal Temperature: **70°F**
 Properties Measured:
 Average Material Properties (5 Specimens): ^{1,2}
 Poisson’s Ratio, ν_{xz} : **0.0019**
 Poisson’s Ratio, ν_{yz} : **0.2678**

| Specimen | Max Stress, σ_z ³ (psi) | Tensile Modulus, E_z (psi) | Poisson’s Ratio | | Failure Mode ⁴ |
|-------------------|--|---------------------------------|-----------------|---------------|---------------------------|
| | | | ν_{xz} | ν_{yz} | |
| MAT6-OP-1-70-FY09 | 2,331 | 908,342 | -0.004396 | 0.398811 | Rupture |
| MAT6-OP-2-70-FY09 | 2,410 | 983,913 | 0.010618 | 0.253585 | Bondline |
| MAT6-OP-3-70-FY09 | 2,118 | 755,505 | -0.034419 | 0.226029 | Bondline |
| MAT6-OP-4-70-FY09 | 2,773 | 1,128,536 | 0.047034 | 0.302994 | Bondline |
| MAT6-OP-5-70-FY09 | 3,293 | 1,050,166 | -0.009488 | 0.157651 | Rupture |
| Average | 2,585 | 965,292 | 0.0019 | 0.2678 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Dissimilar from other materials part of this research, the ν_{xz} and ν_{yz} Poisson’s ratio results varied significantly for Material 6-FY09 (often negative). Therefore, strain gauges are used to measure longitudinal and transverse strain on all four sides of the specimen. Two are used to measure ν_{xz} and two are used to measure ν_{yz} . The orientation of each axis is shown with a picture of a specimen which also indicates which property is measured on each of the four sides. As shown in the picture, horizontal black lines are evident on Sides 1 and 3.

70°F Temperature Test Condition**Nominal Dimensions****Picture, Strain Gauges Config.**

Top end tab removed for picture

Notes:

- 1) Reference I-116 thru I-120 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Max stress achieved during each test.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 5) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-1-70-FY09**
 Test Date: 12/14/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

Average Material Properties:

Maximum Stress, σ_z :¹ 3,184 psi
 Poisson's Ratio, v_{xz} : -0.0044
 Poisson's Ratio, v_{yz} : 0.3988

Specimen Data:

Thickness: 0.750 in
 Side 1: 0.996 in
 Side 2: 0.998 in
 Test Max Stress:² 2,331 psi
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



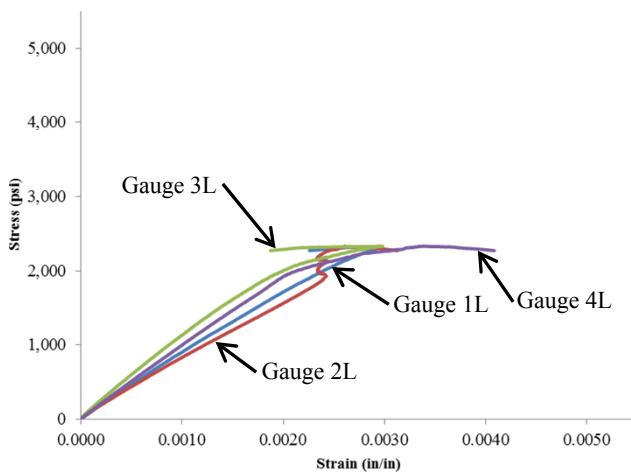
PICTURE OF SPECIMEN POST-TEST



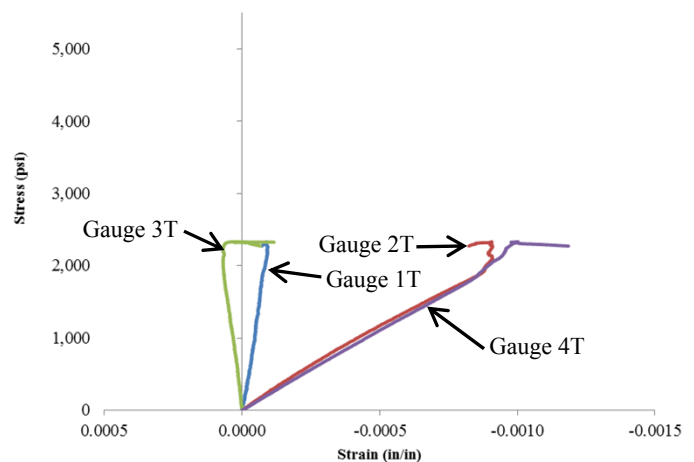
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|--------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001790 | 0.000669 | 852,598 | 1T (x) | -0.000065 | -0.000030 | 0.0306 |
| 2L | 0.001982 | 0.000724 | 759,473 | 2T (y) | -0.000690 | -0.000248 | 0.3515 |
| 3L | 0.001425 | 0.000515 | 1,049,319 | 3T (x) | 0.000053 | 0.000018 | -0.0394 |
| 4L | 0.001590 | 0.000607 | 971,978 | 4T (y) | -0.000714 | -0.000276 | 0.4461 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0044 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.3988 |

Stress-Strain Curve_70_1_(09-06)_Long



Stress-Strain Curve_70_1_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-70-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-70-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-2-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

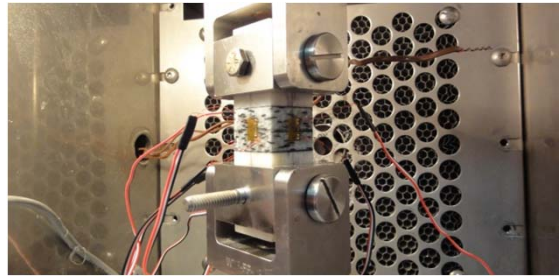
Average Material Properties:

Maximum Stress, σ_z : ¹ 3,184 psi
 Poisson's Ratio, v_{xz} : 0.0106
 Poisson's Ratio, v_{yz} : 0.2536

Specimen Data:

Thickness: 0.750 in
 Side 1: 0.998 in
 Side 2: 0.998 in
 Test Max Stress: ² 2,410 psi
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



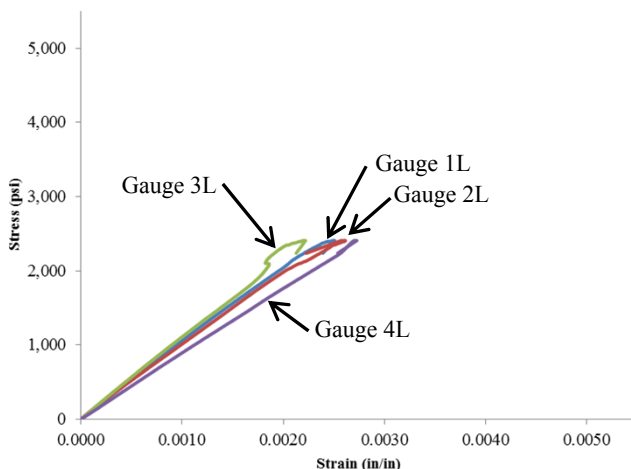
PICTURE OF SPECIMEN POST-TEST



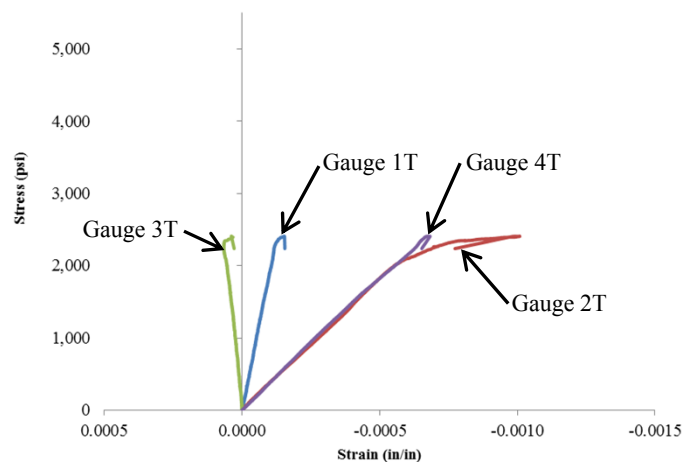
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001530 | 0.000597 | 1,023,284 | 1T (x) | -0.000083 | -0.000035 | 0.0518 |
| 2L | 0.001587 | 0.000616 | 983,338 | 2T (y) | -0.000436 | -0.000174 | 0.2697 |
| 3L | 0.001468 | 0.000561 | 1,052,996 | 3T (x) | 0.000042 | 0.000014 | -0.0306 |
| 4L | 0.001799 | 0.000709 | 876,035 | 4T (y) | -0.000428 | -0.000169 | 0.2375 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0106 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.2536 |

Stress-Strain Curve_70_2_(09-06)_Long



Stress-Strain Curve_70_2_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-70-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-70-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-3-70-FY09**
 Test Date: 12/16/2011
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

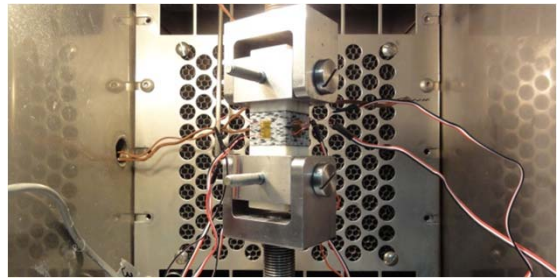
Average Material Properties:

Maximum Stress, σ_z :¹ 3,184 psi
 Poisson's Ratio, v_{xz} : -0.0344
 Poisson's Ratio, v_{yz} : 0.2260

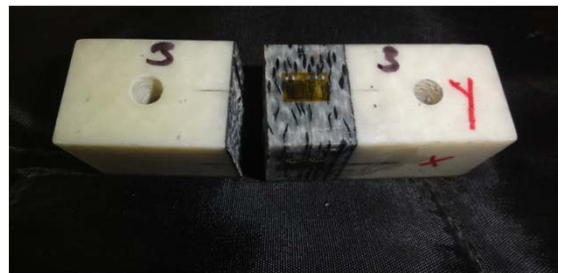
Specimen Data:

Thickness: 0.750 in
 Side 1: 0.996 in
 Side 2: 0.998 in
 Test Max Stress:² 2,118 psi
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



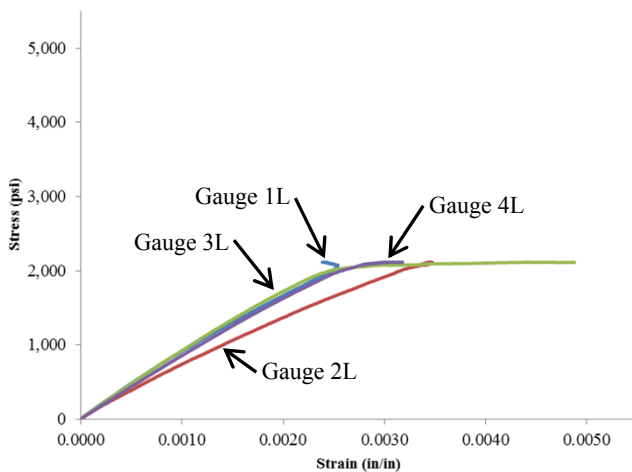
PICTURE OF SPECIMEN POST-TEST



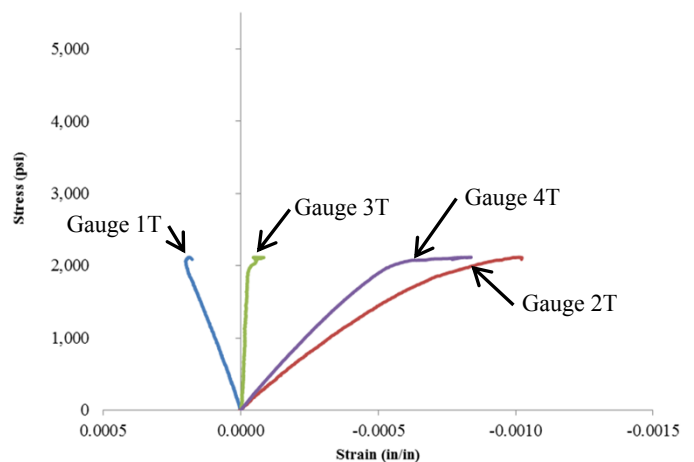
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|--------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001892 | 0.000669 | 780,757 | 1T (x) | 0.000155 | 0.000059 | -0.0790 |
| 2L | 0.002381 | 0.000844 | 621,652 | 2T (y) | -0.000567 | -0.000194 | 0.2425 |
| 3L | 0.001816 | 0.000669 | 833,014 | 3T (x) | -0.000022 | -0.000011 | 0.0101 |
| 4L | 0.001946 | 0.000732 | 786,597 | 4T (y) | -0.000398 | -0.000143 | 0.2095 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0344 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.2260 |

Stress-Strain Curve_70_3_(09-06)_Long



Stress-Strain Curve_70_3_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-70-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-70-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-4-70-FY09**
 Test Date: 5/1/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

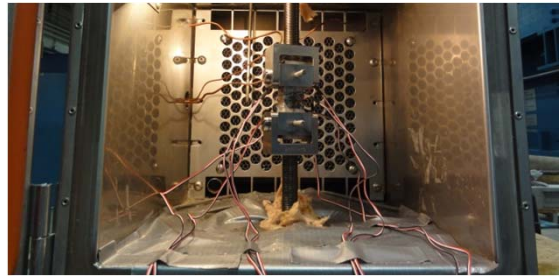
Average Material Properties:

Maximum Stress, σ_z :¹ 3,184 psi
 Poisson's Ratio, v_{xz} : 0.0470
 Poisson's Ratio, v_{yz} : 0.3030

Specimen Data:

Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 0.998 in
 Test Max Stress:² 2,773 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



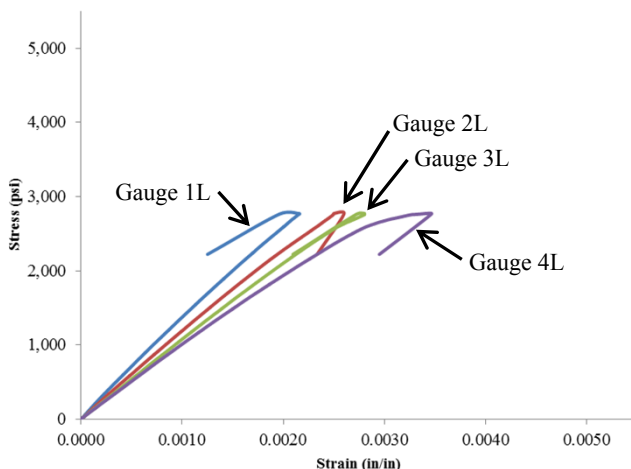
PICTURE OF SPECIMEN POST-TEST



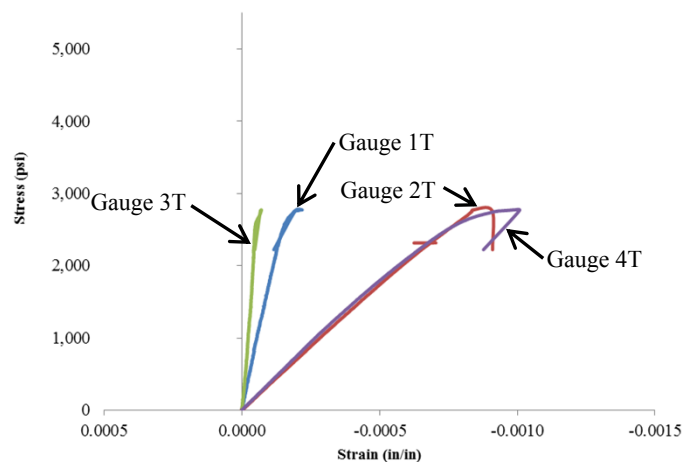
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001169 | 0.000446 | 1,322,036 | 1T (x) | -0.000087 | -0.000034 | 0.0733 |
| 2L | 0.001351 | 0.000526 | 1,157,600 | 2T (y) | -0.000456 | -0.000180 | 0.3340 |
| 3L | 0.001488 | 0.000592 | 1,064,992 | 3T (x) | -0.000034 | -0.000015 | 0.0207 |
| 4L | 0.001611 | 0.000625 | 969,514 | 4T (y) | -0.000436 | -0.000168 | 0.2720 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | 0.0470 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.3030 |

Stress-Strain Curve_70_4_(09-06)_Long



Stress-Strain Curve_70_4_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-70-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-70-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-5-70-FY09**
 Test Date: 5/2/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

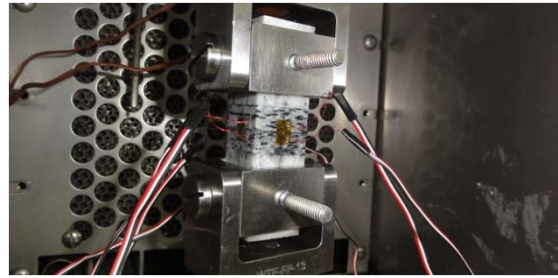
Average Material Properties:

Maximum Stress, σ_z :¹ 3,184 psi
 Poisson's Ratio, v_{xz} : -0.0095
 Poisson's Ratio, v_{yz} : 0.1577

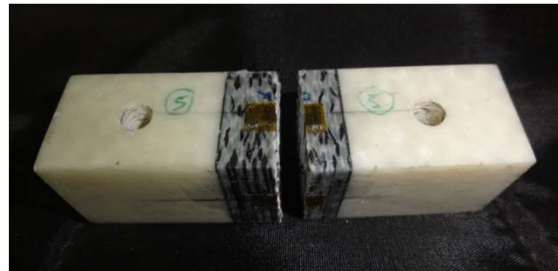
Specimen Data:

Thickness: 0.750 in
 Side 1: 0.984 in
 Side 2: 0.983 in
 Test Max Stress:² 3,293 psi
 Failure Mode: Rupture

PICTURE OF SPECIMEN PRE-TEST



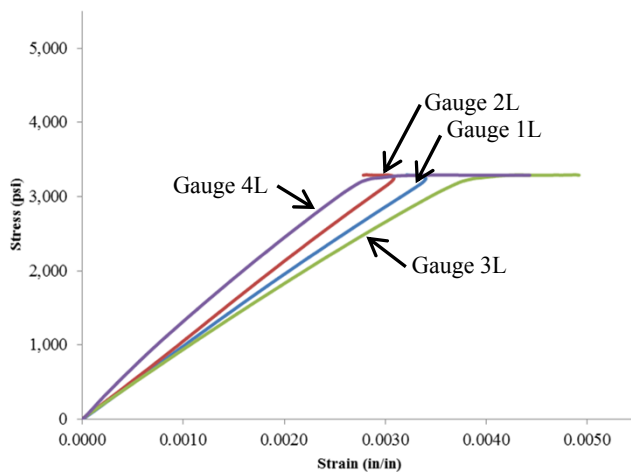
PICTURE OF SPECIMEN POST-TEST



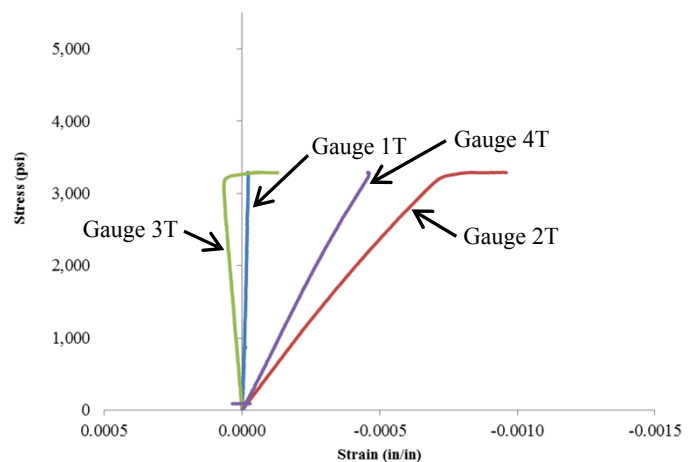
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 50% Max Stress | Strain @ 20% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001494 | 0.000611 | 1,081,419 | 1T (x) | -0.000014 | -0.000007 | 0.0080 |
| 2L | 0.001727 | 0.000669 | 903,311 | 2T (y) | -0.000323 | -0.000127 | 0.1861 |
| 3L | 0.001232 | 0.000456 | 1,230,755 | 3T (x) | 0.000035 | 0.000014 | -0.0270 |
| 4L | 0.001618 | 0.000648 | 985,180 | 4T (y) | -0.000212 | -0.000087 | 0.1292 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0095 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.1577 |

Stress-Strain Curve_70_5_(09-06)_Long



Stress-Strain Curve_70_5_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-70-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 20% and 50% of max load (based on MAT6-TZ-70-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

MATERIAL TESTING SUMMARY SHEET- Out-Of-Plane Poisson Ratio Test

TEST: (*Modified ASTM D7291/D7291M-07) *Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material

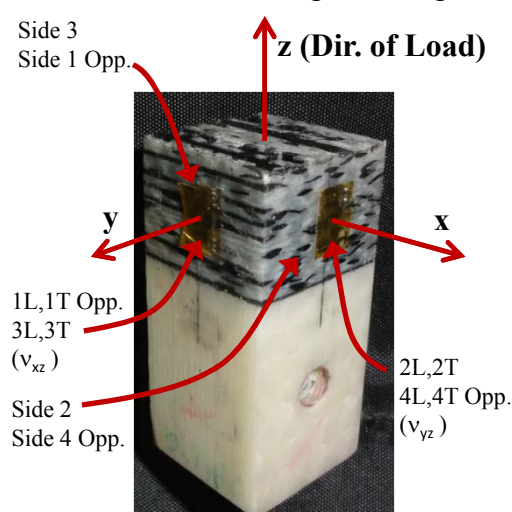
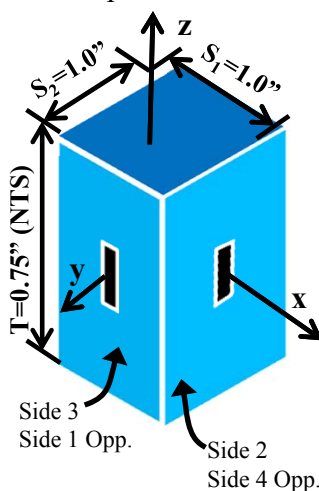
TEST SUMMARY/RESULTS –AVERAGE OF 5 SPECIMENS

Specimen ID Group: **MAT6-OP-140-FY09**
 Material: **Huntsman Epoxies Rn 8605, Ductile Hybrid Fabric**
 Nominal Temperature: **140°F**
 Properties Measured:
 Average Material Properties (5 Specimens): ^{1,2}
 Poisson’s Ratio, ν_{xz} : **-0.0820**
 Poisson’s Ratio, ν_{yz} : **0.3210**

| Specimen | Max Stress, σ_z ³ (psi) | Tensile Modulus, E_z (psi) | Poisson’s Ratio | | Failure Mode ⁴ |
|--------------------|--|---------------------------------|-----------------|---------------|---------------------------|
| | | | ν_{xz} | ν_{yz} | |
| MAT6-OP-1-140-FY09 | 709 | 135,137 | -0.066834 | 0.275874 | Bondline |
| MAT6-OP-2-140-FY09 | 1,390 | 303,149 | -0.048880 | 0.380757 | Bondline |
| MAT6-OP-3-140-FY09 | 764 | 170,914 | -0.128834 | 0.447418 | Bondline |
| MAT6-OP-4-140-FY09 | 1,429 | 340,864 | -0.077606 | 0.325507 | Bondline |
| MAT6-OP-5-140-FY09 | 777 | 161,195 | -0.088012 | 0.175508 | Bondline |
| Average | 1,014 | 222,252 | -0.0820 | 0.3210 | |

Test Description:

The out-of-plane Poisson’s Ratio Test is conducted using a modified version of ASTM D7291/D7291M “Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material”. Instead of using a cylindrical specimen, a block specimen is used to perform the test. The block dimensions are 1” X 1” X 0.75”. The test is performed on the Instron 8502A, which has a double pivot test fixture attached to the upper and lower heads allowing for universal tension throughout the specimen. Dissimilar from other materials part of this research, the ν_{xz} and ν_{yz} Poisson’s ratio results varied significantly for Material 6-FY09 (often negative). Therefore, strain gauges are used to measure longitudinal and transverse strain on all four sides of the specimen. Two are used to measure ν_{xz} and two are used to measure ν_{yz} . The orientation of each axis is shown with a picture of a specimen which also indicates which property is measured on each of the four sides. As shown in the picture, horizontal black lines are evident on Sides 1 and 3.

140°F Temperature Test Condition**Nominal Specimen Dimensions****Picture, Strain Gauges Config.****Notes:**

- 1) Reference I-122 thru I-126 for individual specimen data.
- 2) 5 specimens tested, group of 5 specimens with representative data to report.
- 3) Max stress achieved during each test.
- 4) Bondline failure refers to ASTM failure of less than 1 ply from the epoxied specimen at the base.
- 5) Rupture failure refers to ASTM failure of more than 1 ply from the epoxied specimen at the base.

Top end tab removed for picture

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-1-140-FY09**
 Test Date: 2/20/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

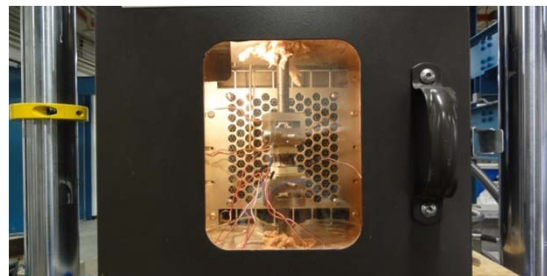
Average Material Properties:

Maximum Stress, σ_z :¹ 1,601 psi
 Poisson's Ratio, v_{xz} : -0.0668
 Poisson's Ratio, v_{yz} : 0.2759

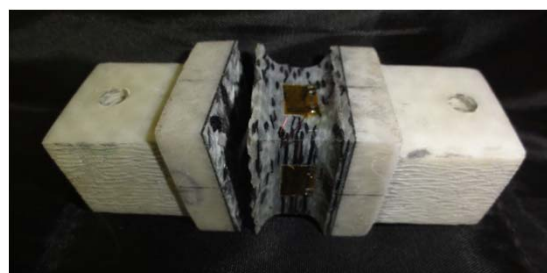
Specimen Data:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 0.999 in
 Test Max Stress:² 709 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



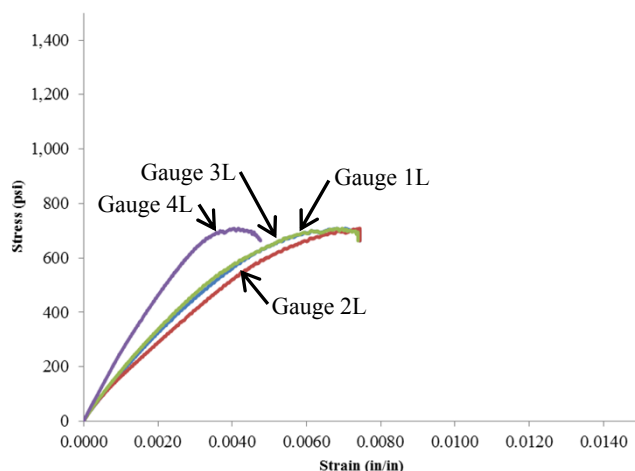
PICTURE OF SPECIMEN POST-TEST



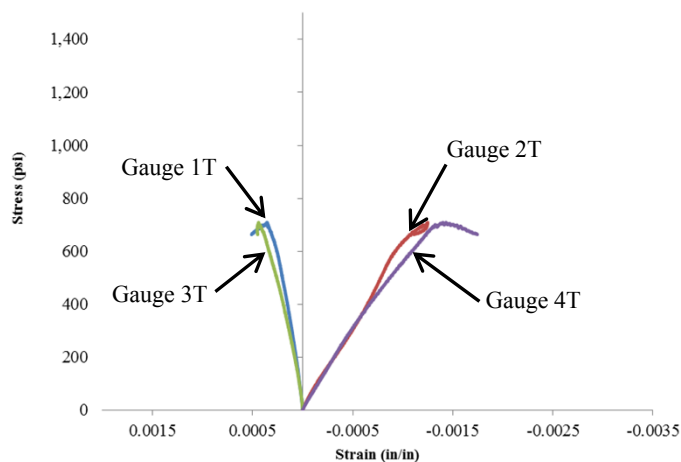
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|--------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | Tensile Modulus E_z | Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.004923 | 0.000889 | 119,062 | 1T (x) | 0.000286 | 0.000050 | -0.0585 |
| 2L | 0.005530 | 0.000957 | 105,043 | 2T (y) | -0.001010 | -0.000241 | 0.1682 |
| 3L | 0.004905 | 0.000842 | 118,235 | 3T (x) | 0.000364 | 0.000058 | -0.0752 |
| 4L | 0.003035 | 0.000612 | 198,210 | 4T (y) | -0.001178 | -0.000249 | 0.3835 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0668 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.2759 |

Stress-Strain Curve_140_1_(09-06)_Long



Stress-Strain Curve_140_1_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-140-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 10% and 40% of max load (based on MAT6-TZ-140-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-2-140-FY09**
 Test Date: 2/20/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

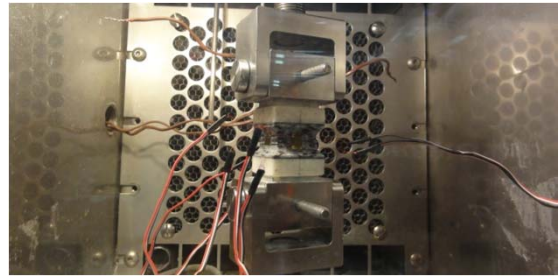
Average Material Properties:

Maximum Stress, σ_z :¹ 1,601 psi
 Poisson's Ratio, v_{xz} : -0.0489
 Poisson's Ratio, v_{yz} : 0.3808

Specimen Data:

Thickness: 0.750 in
 Side 1: 1.002 in
 Side 2: 0.998 in
 Test Max Stress:² 1,390 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST

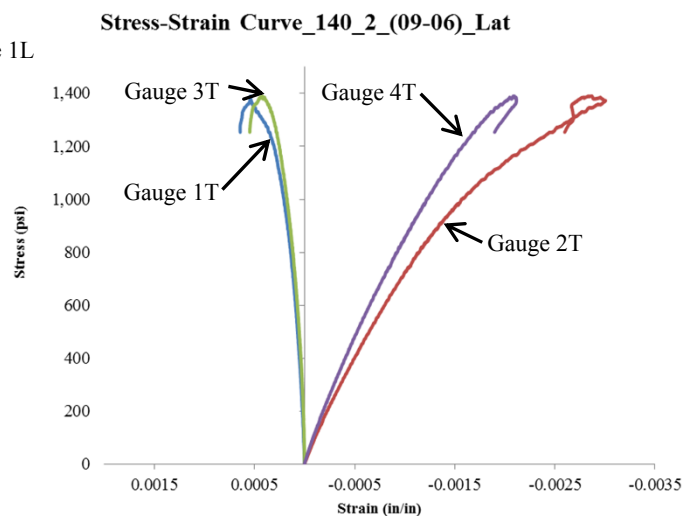
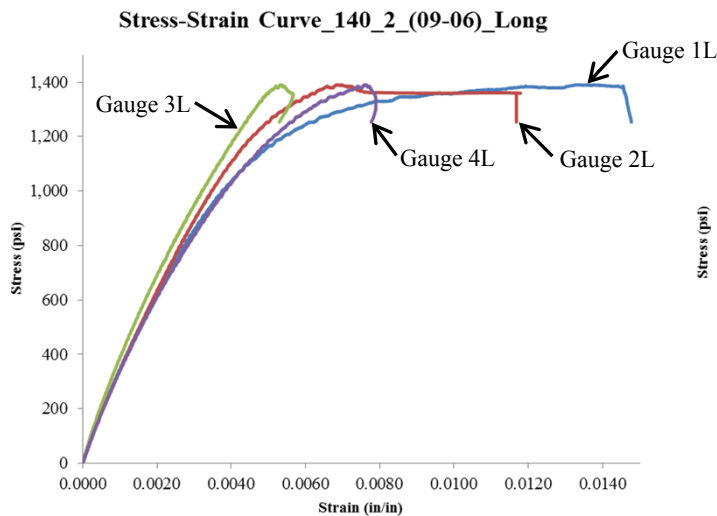


PICTURE OF SPECIMEN POST-TEST



INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|--------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | Tensile Modulus E_z | Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.002058 | 0.000428 | 294,685 | 1T (x) | 0.000099 | 0.000017 | -0.0499 |
| 2L | 0.002022 | 0.000436 | 302,780 | 2T (y) | -0.000862 | -0.000177 | 0.4316 |
| 3L | 0.001818 | 0.000363 | 329,981 | 3T (x) | 0.000080 | 0.000010 | -0.0479 |
| 4L | 0.002119 | 0.000435 | 285,151 | 4T (y) | -0.000701 | -0.000145 | 0.3299 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0489 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.3808 |



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-140-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 10% and 40% of max load (based on MAT6-TZ-140-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-3-140-FY09**
 Test Date: 2/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

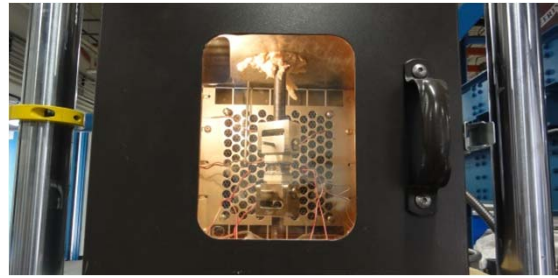
Average Material Properties:

Maximum Stress, σ_z :¹ 1,601 psi
 Poisson's Ratio, v_{xz} : -0.1288
 Poisson's Ratio, v_{yz} : 0.4474

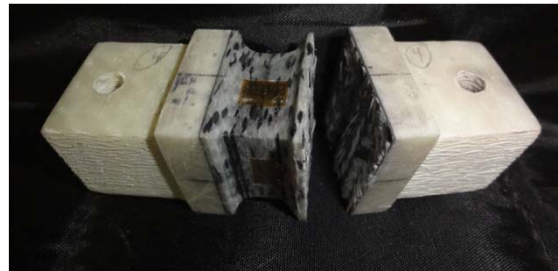
Specimen Data:

Thickness: 0.750 in
 Side 1: 0.999 in
 Side 2: 0.999 in
 Test Max Stress:² 764 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



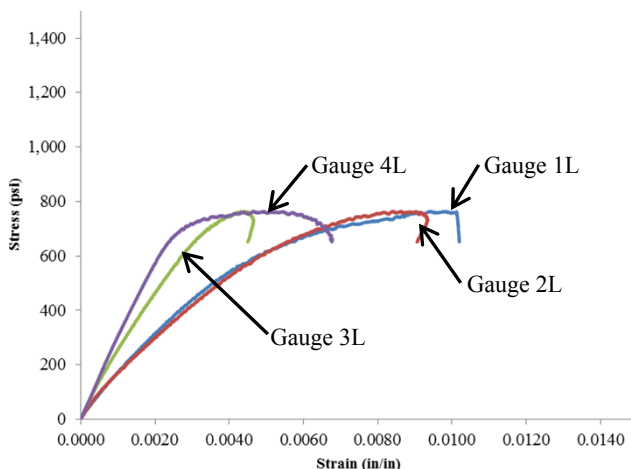
PICTURE OF SPECIMEN POST-TEST



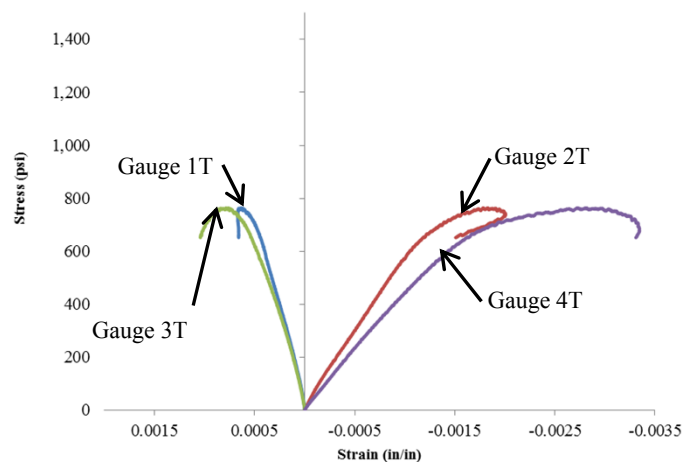
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|-----------------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | Tensile Modulus E_z (psi) | Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.005428 | 0.000915 | 106,412 | 1T (x) | 0.000428 | 0.000078 | -0.0776 |
| 2L | 0.005383 | 0.000920 | 107,613 | 2T (y) | -0.001150 | -0.000243 | 0.2032 |
| 3L | 0.002969 | 0.000580 | 201,053 | 3T (x) | 0.000518 | 0.000087 | -0.1801 |
| 4L | 0.002301 | 0.000512 | 268,578 | 4T (y) | -0.001573 | -0.000337 | 0.6916 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.1288 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.4474 |

Stress-Strain Curve_140_3_(09-06)_Long



Stress-Strain Curve_140_3_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-140-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 10% and 40% of max load (based on MAT6-TZ-140-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-4-140-FY09**
 Test Date: 2/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

Average Material Properties:

Maximum Stress, σ_z :¹ 1,601 psi
 Poisson's Ratio, v_{xz} : -0.0776
 Poisson's Ratio, v_{yz} : 0.3255

Specimen Data:

Thickness: 0.750 in
 Side 1: 1.001 in
 Side 2: 1.002 in
 Test Max Stress:² 1,429 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



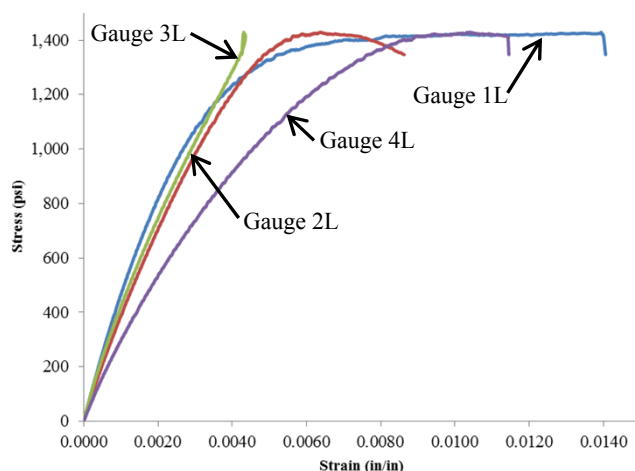
PICTURE OF SPECIMEN POST-TEST



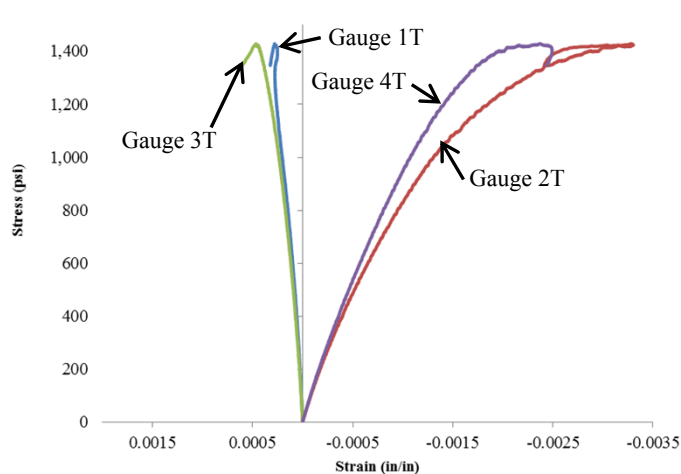
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|----------------------------|----------------------------|--------------------------|----------------|----------------------------|----------------------------|-----------------|
| Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | Tensile Modulus E_z | Gauge | Strain @ 40% Max Stress | Strain @ 10% Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.001461 | 0.000316 | 419,194 | 1T (x) | 0.000108 | 0.000020 | -0.0770 |
| 2L | 0.001782 | 0.000381 | 342,612 | 2T (y) | -0.000708 | -0.000138 | 0.4062 |
| 3L | 0.001654 | 0.000326 | 361,445 | 3T (x) | 0.000128 | 0.000024 | -0.0782 |
| 4L | 0.002501 | 0.000502 | 240,206 | 4T (y) | -0.000618 | -0.000129 | 0.2448 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0776 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.3255 |

Stress-Strain Curve_140_4_(09-06)_Long



Stress-Strain Curve_140_4_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-140-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 10% and 40% of max load (based on MAT6-TZ-140-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

TEST: Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber Reinforced Polymer Matrix Composite Material(*Modified ASTM D7291/D7291M-07)

TEST SUMMARY

Specimen ID: **MAT6-OP-5-140-FY09**
 Test Date: 2/21/2012
 Specimen Received: 10/31/2011
 Properties Measured: v_{xz} , v_{yz}

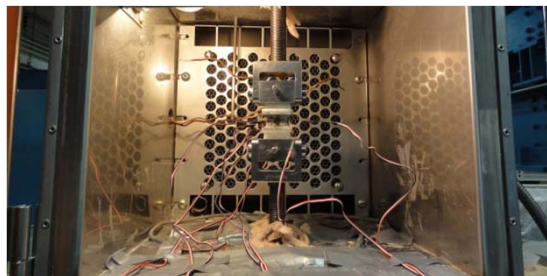
Average Material Properties:

Maximum Stress, σ_z :¹ 1,601 psi
 Poisson's Ratio, v_{xz} : -0.0880
 Poisson's Ratio, v_{yz} : 0.1755

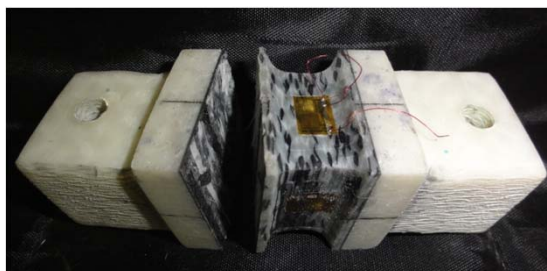
Specimen Data:

Thickness: 0.750 in
 Side 1: 1.000 in
 Side 2: 1.000 in
 Test Max Stress:² 777 psi
 Failure Mode: Bondline

PICTURE OF SPECIMEN PRE-TEST



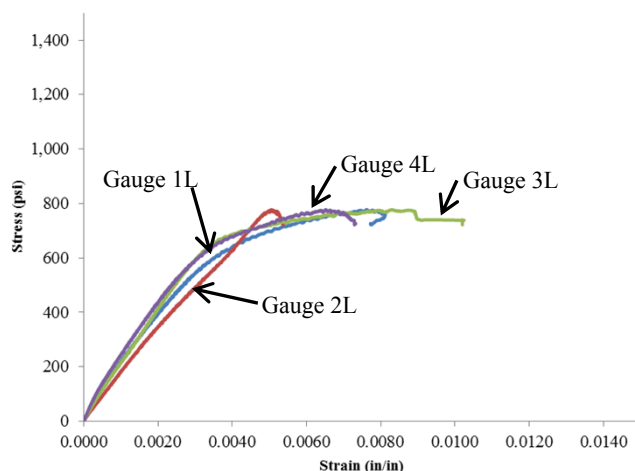
PICTURE OF SPECIMEN POST-TEST



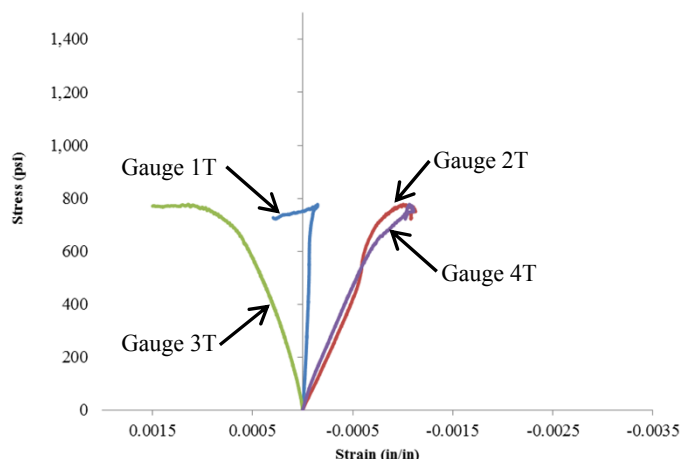
INDIVIDUAL STRAIN GAUGE RESULTS

| Longitudinal Gauges | | | | Lateral Gauges | | | Poisson's Ratio |
|--------------------------------------|--------------|--------------|--------------------------|----------------|--------------|--------------|-----------------|
| Gauge | Strain @ 40% | Strain @ 10% | Tensile Modulus E_z | Gauge | Strain @ 40% | Strain @ 10% | |
| | Max Stress | Max Stress | | | Max Stress | Max Stress | |
| | (in/in) | (in/in) | | | (in/in) | (in/in) | |
| 1L | 0.003989 | 0.000699 | 146,000 | 1T (x) | -0.000070 | -0.000027 | 0.0130 |
| 2L | 0.004070 | 0.000871 | 150,146 | 2T (y) | -0.000656 | -0.000198 | 0.1432 |
| 3L | 0.003359 | 0.000707 | 181,153 | 3T (x) | 0.000591 | 0.000090 | -0.1890 |
| 4L | 0.003460 | 0.000592 | 167,481 | 4T (y) | -0.000742 | -0.000146 | 0.2078 |
| Average from Sides 1,3 (v_{xz}): | | | | | | | -0.0880 |
| Average from Sides 2,4 (v_{yz}): | | | | | | | 0.1755 |

Stress-Strain Curve_140_5_(09-06)_Long



Stress-Strain Curve_140_5_(09-06)_Lat



Engineering Test notes:

- 1) *Maximum Stress* refers to the max stress determined from MAT6-TZ-140-FY09 strength data.
- 2) *Test Max Stress* refers to the max stress reached during the current test.
- 3) The specimen was fitted with four Vishay C2A-06-125LT-350 strain gauges, one on each side.
- 4) Poisson's Ratio was calculated using the strain values at 10% and 40% of max load (based on MAT6-TZ-140-FY09 data)
- 5) Strain and Load data were recorded using a Titan Mini-recorder (calibrated 6-3-10)

UNCLASSIFIED

APPENDIX J

STATISTICAL RESULTS

UNCLASSIFIED

Material 1-FY08

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-1: Results Material 1-FY08, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y | 51,720 | 48,035 | 42,203 | 677 | 1,778 | 600 | 1.3 | 3.7 | 1.4 |
| | E _x or E _y | 2,399,400 | 2,168,333 | 2,180,534 | 177,768 | 98,205 | 110,121 | 7.4 | 4.5 | 5.1 |
| | v _{xy} | 0.250 | 0.213 | 0.267 | 0.027 | 0.015 | 0.018 | 10.9 | 6.9 | 6.8 |
| In-Plane Compression | SC _x or SC _y | 45,804 | 40,268 | 33,235 | 1,268 | 1,177 | 611 | 2.8 | 2.9 | 1.8 |
| | EC _x or EC _y | 2,861,819 | 2,870,964 | 2,692,783 | 167,643 | 124,769 | 200,962 | 5.9 | 4.3 | 7.5 |
| | vC _{xy} | 0.312 | 0.325 | 0.319 | 0.036 | 0.042 | 0.063 | 11.4 | 13.0 | 19.6 |
| In-Plane Shear | S _{xy} | 37,620 | 31,056 | 27,809 | 574 | 900 | 689 | 1.5 | 2.9 | 2.5 |
| | G _{xy} | 1,429,514 | 1,313,712 | 1,221,689 | 101,965 | 140,732 | 39,554 | 7.1 | 10.7 | 3.2 |
| Out-of-Plane Tension | ST _z | 5,028 | 4,347 | 3,888 | 354 | 146 | 106 | 7.0 | 3.4 | 2.7 |
| | E _z | 1,465,000 | 1,424,406 | 1,106,657 | 75,460 | 64,412 | 62,589 | 5.2 | 4.5 | 5.7 |
| Out-of-Plane Compression | SC _z | 100,317 | 80,317 | 65,994 | 4,705 | 4,666 | 1,679 | 4.7 | 5.8 | 2.5 |
| | EC _z | 1,921,878 | 1,422,605 | 1,233,110 | 75,980 | 104,494 | 54,352 | 4.0 | 7.3 | 4.4 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 4,571 | 3,804 | 3,087 | 58 | 550 | 219 | 1.3 | 14.5 | 7.1 |
| | G _{xz} or G _{yz} | 837,401 | 864,066 | 700,184 | 51,821 | 65,623 | 117,120 | 6.2 | 7.6 | 16.7 |
| OP Poisson | v _{xz} or v _{yz} | 0.170 | 0.185 | 0.119 | 0.037 | 0.028 | 0.013 | 21.9 | 15.0 | 10.6 |

Material 2-FY08

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-2: Results Material 2-FY08, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|--------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|---------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or Sty | 54,330 | 45,226 | 31,910 | 2,422 | 830 | 872 | 4.5 | 1.8 | 2.7 |
| | E _x or Ey | 2,286,416 | 1,986,366 | 1,656,583 | 105,832 | 127,154 | 300,727 | 4.6 | 6.4 | 18.2 |
| | v _{xy} | 0.189 | 0.211 | 0.177 | 0.045 | 0.045 | 0.056 | 23.8 | 21.3 | 31.6 |
| In-Plane Compression | SC _x or SC _y | 37,486 | 25,009 | 12,826 | 2,402 | 1,703 | 1,767 | 6.4 | 6.8 | 13.8 |
| | EC _x or EC _y | 2,692,235 | 2,717,877 | 2,340,062 | 156,680 | 101,221 | 302,147 | 5.8 | 3.7 | 12.9 |
| | vC _{xy} | 0.290 | 0.297 | 0.279 | 0.035 | 0.058 | 0.157 | 12.1 | 19.6 | 56.3 |
| In-Plane Shear | S _{xy} | 23,690 | 21,685 | 17,690 | 2,282 | 344 | 490 | 9.6 | 1.6 | 2.8 |
| | G _{xy} | 1,241,458 | 1,280,563 | 846,113 | 130,650 | 59,002 | 82,572 | 10.5 | 4.6 | 9.8 |
| Out-of-Plane Tension | ST _z | 4,970 | 3,623 | 1,905 | 269 | 228 | 106 | 5.4 | 6.3 | 5.6 |
| | E _z | 1,303,324 | 1,077,526 | 230,915 | 62,109 | 47,319 | 22,274 | 4.8 | 4.4 | 9.6 |
| Out-of-Plane Compression | SC _z | 65,513 | 56,040 | 46,393 | 10,131 | 3,151 | 2,495 | 15.5 | 5.6 | 5.4 |
| | EC _z | 1,165,695 | 1,028,310 | 969,253 | 114,248 | 106,178 | 113,426 | 9.8 | 10.3 | 11.7 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 5,360 | 3,064 | 1,053 | 109 | 81 | 61 | 2.0 | 2.6 | 5.8 |
| | G _{xz} or G _{yz} | 394,355 | 272,697 | 20,012 | 20,923 | 17,910 | 3,091 | 5.3 | 6.6 | 15.4 |
| OP Poisson | v _{xz} or v _{yz} | 0.113 | 0.132 | -0.037 | 0.030 | 0.019 | 0.028 | 26.6 | 14.4 | -76.3 |

Material 1-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-3: Results Material 1-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y | 51,176 | 45,188 | 33,951 | 1,498 | 1,169 | 2,528 | 2.9 | 2.6 | 7.4 |
| | E _x or E _y | 2,225,572 | 2,036,734 | 1,528,496 | 49,639 | 38,463 | 206,121 | 2.2 | 1.9 | 13.5 |
| | v _{xy} | 0.267 | 0.249 | 0.268 | 0.038 | 0.075 | 0.174 | 14.4 | 30.0 | 64.9 |
| In-Plane Compression | SC _x or SC _y | 39,116 | 26,453 | 11,890 | 1,415 | 1,703 | 1,912 | 3.6 | 6.4 | 16.1 |
| | EC _x or EC _y | 2,877,581 | 2,796,012 | 2,298,234 | 133,225 | 59,369 | 175,820 | 4.6 | 2.1 | 7.7 |
| | vC _{xy} | 0.253 | 0.262 | 0.298 | 0.043 | 0.068 | 0.114 | 17.0 | 26.0 | 38.2 |
| In-Plane Shear | S _{xy} | 30,763 | 23,625 | 15,145 | 624 | 659 | 2,048 | 2.0 | 2.8 | 13.5 |
| | G _{xy} | 1,364,919 | 1,336,103 | 1,034,024 | 61,326 | 64,998 | 124,148 | 4.5 | 4.9 | 12.0 |
| Out-of-Plane Tension | ST _z | 4,604 | 3,096 | 1,893 | 417 | 254 | 127 | 9.1 | 8.2 | 6.7 |
| | E _z | 1,140,678 | 931,037 | 334,720 | 77,516 | 17,716 | 31,944 | 6.8 | 1.9 | 9.5 |
| Out-of-Plane Compression | SC _z | 71,548 | 57,795 | 50,439 | 3,072 | 1,226 | 793 | 4.3 | 2.1 | 1.6 |
| | EC _z | 1,231,113 | 1,080,657 | 1,174,700 | 70,744 | 202,392 | 180,892 | 5.7 | 18.7 | 15.4 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 4,620 | 2,720 | 931 | 159 | 119 | 44 | 3.4 | 4.4 | 4.7 |
| | G _{xz} or G _{yz} | 19,437 | 460,711 | 601,889 | 3,781 | 43,653 | 23,498 | 19.5 | 9.5 | 3.9 |
| OP Poisson | v _{xz} or v _{yz} | 0.158 | 0.137 | 0.118 | 0.034 | 0.019 | 0.034 | 21.4 | 13.7 | 29.1 |

Material 2-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-4: Results Material 2-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or Sty | 45,714 | 43,257 | 32,303 | 1,105 | 496 | 1,901 | 2.4 | 1.1 | 5.9 |
| | E _x or Ey | 2,100,891 | 1,784,110 | 1,578,155 | 48,482 | 90,101 | 240,656 | 2.3 | 5.1 | 15.2 |
| | v _{xy} | 0.216 | 0.248 | 0.397 | 0.012 | 0.034 | 0.070 | 5.4 | 13.5 | 17.6 |
| In-Plane Compression | SC _x or SC _y | 36,806 | 26,695 | 10,486 | 1,926 | 1,083 | 228 | 5.2 | 4.1 | 2.2 |
| | EC _x or EC _y | 2,839,855 | 2,730,500 | 2,244,152 | 130,421 | 110,234 | 190,886 | 4.6 | 4.0 | 8.5 |
| | vC _{xy} | 0.246 | 0.206 | 0.297 | 0.029 | 0.022 | 0.033 | 11.8 | 10.5 | 11.0 |
| In-Plane Shear | S _{xy} | 28,345 | 19,104 | 10,301 | 1,021 | 981 | 557 | 3.6 | 5.1 | 5.4 |
| | G _{xy} | 1,316,192 | 1,262,899 | 910,531 | 92,604 | 105,779 | 105,441 | 7.0 | 8.4 | 11.6 |
| Out-of-Plane Tension | ST _z | 4,477 | 3,304 | 1,602 | 202 | 176 | 128 | 4.5 | 5.3 | 8.0 |
| | E _z | 1,121,661 | 985,645 | 264,627 | 44,849 | 51,523 | 51,708 | 4.0 | 5.2 | 19.5 |
| Out-of-Plane Compression | SC _z | 69,614 | 51,851 | 48,680 | 5,477 | 2,158 | 673 | 7.9 | 4.2 | 1.4 |
| | EC _z | 1,107,757 | 805,102 | 896,758 | 113,166 | 88,682 | 100,344 | 10.2 | 11.0 | 11.2 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 4,780 | 2,923 | 1,019 | 164 | 232 | 46 | 3.4 | 8.0 | 4.5 |
| | G _{xz} or G _{yz} | 603,574 | 457,242 | 43,716 | 38,700 | 7,752 | 5,453 | 6.4 | 1.7 | 12.5 |
| OP Poisson | v _{xz} or v _{yz} | 0.153 | 0.174 | 0.132 | 0.009 | 0.035 | 0.063 | 5.8 | 20.0 | 47.6 |

Material 3-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-5: Results Material 3-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or ST _y | 94,461 | 83,782 | 76,055 | 2,069 | 3,074 | 4,024 | 2.2 | 3.7 | 5.3 |
| | E _x or E _y | 2,923,745 | 3,061,313 | 2,939,731 | 228,185 | 163,827 | 300,872 | 7.8 | 5.4 | 10.2 |
| | ν _{xy} | 0.069 | 0.062 | 0.058 | 0.015 | 0.006 | 0.016 | 21.2 | 9.1 | 27.5 |
| In-Plane Compression | SC _x or SC _y | 68,346 | 45,645 | 34,665 | 2,690 | 2,424 | 1,609 | 3.9 | 5.3 | 4.6 |
| | EC _x or EC _y | 3,786,027 | 3,463,579 | 3,463,828 | 171,661 | 70,442 | 135,650 | 4.5 | 2.0 | 3.9 |
| | νC _{xy} | 0.061 | 0.076 | NA | 0.006 | 0.022 | NA | 9.6 | 29.3 | NA |
| In-Plane Shear | S _{xy} | 27,593 | 23,339 | 20,339 | 874 | 838 | 521 | 3.2 | 3.6 | 2.6 |
| | G _{xy} | 516,117 | 415,404 | 268,588 | 64,746 | 40,114 | 25,635 | 12.5 | 9.7 | 9.5 |
| Out-of-Plane Tension | ST _z | 7,742 | 6,982 | 5,373 | 308 | 238 | 305 | 4.0 | 3.4 | 5.7 |
| | E _z | 1,771,241 | 1,604,104 | 924,527 | 153,982 | 80,145 | 115,813 | 8.7 | 5.0 | 12.5 |
| Out-of-Plane Compression | SC _z | 99,424 | 75,713 | 61,033 | 3,414 | 3,271 | 1,337 | 3.4 | 4.3 | 2.2 |
| | EC _z | 1,471,525 | 1,152,591 | 945,082 | 88,076 | 64,657 | 105,317 | 6.0 | 5.6 | 11.1 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 6,373 | 4,281 | 3,389 | 1,465 | 585 | 547 | 23.0 | 13.7 | 16.2 |
| | G _{xz} or G _{yz} | 406,384 | 339,945 | 213,580 | 44,111 | 25,190 | 24,096 | 10.9 | 7.4 | 11.3 |
| OP Poisson | ν _{xz} or ν _{yz} | 0.104 | 0.127 | 0.075 | 0.013 | 0.012 | 0.011 | 12.3 | 9.8 | 14.7 |

Material 4-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-6: Results Material 4-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or Sty | 53,827 | 49,131 | 43,236 | 1,215 | 1,603 | 920 | 2.3 | 3.3 | 2.1 |
| | E _x or Ey | 2,592,766 | 2,328,807 | 2,243,374 | 83,259 | 103,205 | 100,654 | 3.2 | 4.4 | 4.5 |
| | v _{xy} | 0.257 | 0.218 | 0.277 | 0.019 | 0.017 | 0.010 | 7.5 | 7.9 | 3.7 |
| In-Plane Compression | SC _x or SC _y | 43,680 | 35,065 | 30,672 | 2,847 | 2,178 | 2,824 | 6.5 | 6.2 | 9.2 |
| | EC _x or EC _y | 2,957,847 | 3,010,802 | 2,789,322 | 145,391 | 261,730 | 83,996 | 4.9 | 8.7 | 3.0 |
| | vC _{xy} | 0.263 | 0.257 | 0.250 | 0.027 | 0.021 | 0.038 | 10.1 | 8.2 | 15.1 |
| In-Plane Shear | S _{xy} | 37,942 | 31,530 | 25,399 | 904 | 741 | 1,498 | 2.4 | 2.4 | 5.9 |
| | G _{xy} | 1,840,351 | 1,547,881 | 1,507,830 | 147,388 | 103,237 | 183,765 | 8.0 | 6.7 | 12.2 |
| Out-of-Plane Tension | ST _z | 1,371 | 1,481 | 1,215 | 239 | 304 | 113 | 17.5 | 20.5 | 9.3 |
| | E _z | 1,639,148 | 1,603,490 | 1,291,607 | 216,473 | 106,901 | 135,623 | 13.2 | 6.7 | 10.5 |
| Out-of-Plane Compression | SC _z | 100,873 | 79,906 | 71,303 | 1,415 | 2,947 | 4,612 | 1.4 | 3.7 | 6.5 |
| | EC _z | 1,831,220 | 1,345,276 | 1,459,822 | 91,468 | 94,350 | 161,912 | 5.0 | 7.0 | 11.1 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 3,889 | 3,913 | 3,015 | 208 | 261 | 215 | 5.3 | 6.7 | 7.1 |
| | G _{xz} or G _{yz} | 1,162,624 | 1,045,073 | 779,597 | 112,850 | 123,008 | 60,639 | 9.7 | 11.8 | 7.8 |
| OP Poisson | v _{xz} or v _{yz} | 0.154 | 0.144 | 0.147 | 0.040 | 0.017 | 0.017 | 25.9 | 12.0 | 11.5 |

Material 5-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-7: Results Material 5-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or Sty | 46,837 | 45,551 | 38,130 | 2,198 | 1,337 | 1,234 | 4.7 | 2.9 | 3.2 |
| | E _x or Ey | 2,309,264 | 2,018,539 | 1,910,698 | 18,825 | 93,787 | 61,009 | 0.8 | 4.6 | 3.2 |
| | v _{xy} | 0.242 | 0.264 | 0.216 | 0.035 | 0.045 | 0.040 | 14.6 | 17.1 | 18.4 |
| In-Plane Compression | SC _x or SC _y | 45,159 | 32,687 | 26,120 | 1,325 | 1,288 | 2,183 | 2.9 | 3.9 | 8.4 |
| | EC _x or EC _y | 2,997,734 | 2,890,905 | 2,662,344 | 96,563 | 107,732 | 122,459 | 3.2 | 3.7 | 4.6 |
| | vC _{xy} | 0.261 | 0.256 | 0.276 | 0.033 | 0.007 | 0.029 | 12.5 | 2.7 | 10.4 |
| In-Plane Shear | S _{xy} | 36,915 | 28,755 | 22,764 | 1,692 | 1,106 | 460 | 4.6 | 3.8 | 2.0 |
| | G _{xy} | 1,516,312 | 1,427,879 | 1,312,226 | 85,036 | 69,366 | 38,294 | 5.6 | 4.9 | 2.9 |
| Out-of-Plane Tension | ST _z | 4,476 | 3,947 | 3,417 | 592 | 136 | 304 | 13.2 | 3.4 | 8.9 |
| | E _z | 1,272,445 | 1,248,494 | 1,034,477 | 34,721 | 45,520 | 53,439 | 2.7 | 3.6 | 5.2 |
| Out-of-Plane Compression | SC _z | 110,379 | 88,561 | 77,667 | 5,319 | 2,503 | 4,855 | 4.8 | 2.8 | 6.3 |
| | EC _z | 1,410,032 | 1,185,088 | 1,160,739 | 177,473 | 98,736 | 126,752 | 12.6 | 8.3 | 10.9 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 4,854 | 4,214 | 3,667 | 221 | 166 | 167 | 4.5 | 3.9 | 4.6 |
| | G _{xz} or G _{yz} | 469,174 | 340,799 | 306,779 | 18,630 | 24,011 | 30,358 | 4.0 | 7.0 | 9.9 |
| OP Poisson | v _{xz} or v _{yz} | 0.130 | 0.171 | 0.099 | 0.024 | 0.027 | 0.040 | 18.7 | 15.9 | 40.6 |

Material 6-FY09

Means, Standard Deviations, Coefficients of Variance taken from results of five specimens tested.

Table J-8: Results Material 6-FY09, Means, Standard Deviations, Coefficients of Variances

| Test | Property | Mean Values (psi strength and stiffness) | | | Standard Deviations (psi strength and stiffness) | | | Coefficient of Variance % | | |
|-----------------------------|------------------------------------|---|-----------|-----------|---|---------|---------|------------------------------|------|-------|
| | | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F | -40°F | 70°F | 140°F |
| In-Plane Tension | ST _x or Sty | 59,658 | 44,830 | 35,317 | 3,203 | 2,107 | 4,099 | 5.4 | 4.7 | 11.6 |
| | E _x or Ey | 6,630,993 | 6,799,630 | 5,666,334 | 804,333 | 648,335 | 676,709 | 12.1 | 9.5 | 11.9 |
| | v _{xy} | 0.562 | 0.616 | 0.888 | 0.066 | 0.125 | 0.157 | 11.7 | 20.2 | 17.6 |
| In-Plane Compression | SC _x or SC _y | 41,637 | 27,485 | 12,922 | 1,971 | 1,896 | 1,040 | 4.7 | 6.9 | 8.0 |
| | EC _x or EC _y | 4,367,710 | 5,474,333 | 5,593,651 | 634,722 | 341,634 | 924,196 | 14.5 | 6.2 | 16.5 |
| | vC _{xy} | 0.360 | 0.388 | 0.400 | 0.114 | 0.159 | 0.148 | 31.5 | 40.9 | 37.0 |
| In-Plane Shear | S _{xy} | 24,005 | 18,541 | 11,769 | 1,604 | 336 | 1,105 | 6.7 | 1.8 | 9.4 |
| | G _{xy} | 1,931,198 | 1,954,070 | 1,567,885 | 75,419 | 232,625 | 239,495 | 3.9 | 11.9 | 15.3 |
| Out-of-Plane Tension | ST _z | 3,206 | 3,185 | 1,601 | 264 | 258 | 100 | 8.2 | 8.1 | 6.2 |
| | E _z | 1,085,445 | 975,756 | 370,642 | 22,298 | 52,050 | 65,226 | 2.1 | 5.3 | 17.6 |
| Out-of-Plane Compression | SC _z | 46,546 | 35,111 | 27,001 | 1,064 | 1,641 | 532 | 2.3 | 4.7 | 2.0 |
| | EC _z | 1,081,349 | 935,208 | 799,320 | 69,068 | 59,762 | 46,437 | 6.4 | 6.4 | 5.8 |
| Out-of-Plane Shear | S _{xz} or S _{yz} | 5,052 | 3,399 | 1,417 | 677 | 75 | 257 | 13.4 | 2.2 | 18.2 |
| | G _{xz} or G _{yz} | 362,312 | 273,895 | 79,668 | 10,391 | 26,048 | 21,442 | 2.9 | 9.5 | 26.9 |
| OP Poisson | v _{xz} or v _{yz} | 0.208 | 0.268 | 0.321 | 0.064 | 0.090 | 0.103 | 30.5 | 33.6 | 32.2 |